PNWD-3976

Synthesis of Biological Research on Juvenile Fish Passage and Survival 1990–2006: Ice Harbor Dam

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Final Report

Battelle
Pacific Northwest Division
Richland, Washington 99352

Prepared for
U.S. Army Corps of Engineers, Walla Walla District,
Walla Walla, Washington
Under Biological Services Contract W9127N-06-D-0005
Delivery Order 0002

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Abstract

The U.S. Army Corps of Engineers (Corps), Walla Walla District, has conducted research on fish passage and survival at Ice Harbor Dam to continually improve the conditions fish experience when passing through the dams it operates on the lower Snake and Columbia rivers. The purpose of this document is to synthesize the results of studies conducted from 1990 through 2006 to identify relationships that may help choose operations or configurations that improve juvenile fish passage conditions or survival rates. Results from studies of fish passage and survival were combined with information on the river environment, dam operations, and dam configurations to identify influential factors. Increased spill proportions shortened forebay residence times and increased the proportion of fish approaching the dam near the spillway, but had limited influence on vertical distributions. Increasing spill proportions increased spill passage efficiency and fish passage efficiency but decreased spill passage effectiveness. Fish guidance efficiency declined slightly with increasing spill proportion. A large proportion of fish passed the removable spillway weir (RSW) even though RSW flow was a small proportion of the total. The influence of operations and configurations on dam survival rates was not obvious in available data. Survival rates were high for yearling Chinook salmon, steelhead, and subyearling Chinook salmon passing through the juvenile bypass system, the spillway, or the RSW at Ice Harbor Dam. Turbine survival was lowest, but was still approximately 90%. Steelhead were most susceptible to avian predation, followed by subyearling and yearling Chinook salmon. Direct injury studies found higher injury rates for fish released at the deepest release locations. The value of past studies to evaluate the influence of operations or configurations was limited by the practice of varying both spill proportion and spill pattern among treatments, confounding the influence of these factors.

Acknowledgments

We acknowledge valuable feedback provided by Bob Johnson, Ann Setter, Marvin Shutters, and Tim Wik of the U.S. Army Corps of Engineers, Walla Walla District. Thanks also to Mark Plummer U.S. Army Corps of Engineers, Ice Harbor Dam, for providing the collection counts.

We thank investigators who provided copies of their reports and supplied clarifying information when needed.

Thanks to Jen Monroe for her work integrating the data into the document and updating the citation database.

Acronyms and Abbreviations

BiOp	Biological Opinion
cfs	cubic feet per second
CI	confidence interval
Corps	U.S. Army Corps of Engineers
FGE	fish guidance efficiency
FPE	fish passage efficiency
HA	hydroacoustic
IHR	Ice Harbor Dam
JBS	juvenile bypass system
kcfs	thousand cubic feet per second
LOWESS	LOcally WEighted Scatterplot Smoothing
MOP	minimum operating pool
msl	mean sea level
PIT	passive integrated transponder
PST	Pacific Standard Time
RPE	removable spillway weir passage efficiency
RPS	removable spillway weir passage effectiveness
RSW	removable spillway weir
RT	radio telemetry
SOE	surface outlet passage efficiency
SOS	surface outlet passage effectiveness
SPE	spill passage efficiency
SPS	spill passage effectiveness
STS	submersible traveling screen
TDG	total dissolved gas
VBS	vertical barrier screen

Glossary

2000 BiOp	The Biological Opinion for the Federal Columbia River Power System (FCRPS) issued in 2000
2004 BiOp	The Biological Opinion for the FCRPS issued in 2004
2005 Court Order	Court order issued by the U.S. District Court that required spill at transport projects on the Snake River during summer periods when spill was historically shut off to increase collection for transport
2006 Court Order	Court order issued by the U.S. District Court that required continuing summer spill at transport projects on the Snake River
bulk spill	A pattern of spill where fewer bays are operated with larger gate openings
confidence interval	The range that is expected to include the real value in a specified percentage of trials
dam survival	Survival from the upstream limit of the forebay relative to the survival of reference groups released downstream from the dam
fish guidance efficiency	The proportion of fish entering the turbine intake that are diverted into the JBS by the intake screens (abbreviated as FGE)
fish passage efficiency	Proportion of fish passing via non-turbine routes (abbreviated as FPE)
flat spill	A pattern of spill where relatively uniform gate openings are used at all spillbays
forebay residence time	Time elapsed from the arrival of fish in the forebay to the time of passage
guided	Fish that enter the turbine intakes and are diverted by screens into the juvenile bypass system are considered to have been guided by the screens.
PIT tag	Passive integrated transponder tag detected by equipment in the juvenile bypass system
plunging flow	Spill flow that plunges into the stilling basin
relative survival	Survival from detection within a passage route (spillbay, turbine, or juvenile bypass system) at Ice Harbor Dam and release location of reference groups downstream
removable spillway weir	A structural addition to a spillway that allows water to be discharged over a weir crest, rather than under a spillgate
route survival	Survival of juvenile salmonids detected within a passage route relative to survival of reference fish groups released downstream from the dam
RSW passage effectiveness	The ratio of the proportion of fish passing over the RSW to the proportion of flow passing over the RSW (abbreviated as RPS)

RSW passage efficiency	The percentage of fish passing via the RSW relative to total fish passage (abbreviated as RPE)
Sensor Fish	A data-acquisition device released into fish passage routes to characterize the physical conditions experienced by fish during dam passage
skimming flow	Spillway discharge that skims across the surface of the stilling basin
spill level	The volume or proportion of total river flow discharged over the spillway
spill passage effectiveness	The ratio of the proportion of fish passing by spill routes to the proportion of flow spilled (abbreviated as SPS).
spill passage efficiency	Proportion of fish passing over the spillway (abbreviated as SPE).
spill pattern	The distribution of spill discharge among spill bays.
spring passage period	The period during which the majority of juvenile salmonids passing the dam are yearling Chinook salmon and steelhead
standard error	A measure of the possible error in an estimate. The mean plus or minus 2 standard errors roughly approximates the 95% confidence interval.
submerged traveling screen	A type of screen located within the turbine intake to divert fish away from turbine passage and into the juvenile bypass system
summer passage period	The period during which the majority of juvenile salmonids passing the dam are subyearling Chinook salmon
surface flow outlet	A diverse class of passage structures that allow surface water to pass over a structure, rather than under a regulating gate
tailrace egress time	Elapsed time from dam passage to exit from the tailrace
Tainter gate	Radial-style spill gate
total dissolved gas	The amount of gas dissolved in solution, reported as percent of saturation
undular flow	Spillway discharge creates undulations in the stilling basin
unguided fish passage	Fish that pass through turbines because they were not diverted by the screens into the juvenile bypass system
vertical barrier screen	The screen in the gatewell that allows water to reenter the turbine while diverting fish to orifices that lead into the bypass channel
voluntary spill	The planned passing of water over the spillway of a dam to facilitate passage of juvenile salmon past the project

Contents

Figures

Tables

1.0 Introduction

In seeking to continually improve the conditions juvenile fish experience when passing through the dams it operates on the lower Snake and Columbia rivers, the Walla Walla District of the U.S. Army Corps of Engineers (Corps) has conducted numerous studies of fish passage and survival at Ice Harbor Dam. Studies have investigated the effects of specific dam operations and configurations on juvenile fish to better inform decisions about how to enhance or modify them to further improve fish passage and survival. Synthesis of the results of these studies may identify relationships that could guide decisions toward improved operations and configurations that better meet passage and survival goals. This document is a companion report to the *Preliminary Data Summary 2000–2006: Ice Harbor Dam* (Ham et al. 2008). Like the preceding report, it was prepared for the Corps by Battelle—Pacific Northwest Division.

1.1 Purpose and Scope

This report about Ice Harbor Dam is the first of a series of reports that build and expand upon the preliminary data summary documents for each dam operated by the Walla Walla District of the U.S. Army Corps of Engineers. These synthesis reports analyze the biological data collected during studies conducted from 1990 through 2006 to identify information to support decisions about the future operations and configurations of the dam. Species composition, run timing, season, flow years, fish passage, injury, and survival are examined to find relationships with the configurations and operations of the dam. Understanding the influence of configurations and operations tested in past studies may reveal opportunities for how fish passage or survival goals can be better achieved in the future.

1.2 Species Composition and Run Timing

The timing of the arrival of fish populations at Ice Harbor Dam is influenced by hatchery releases, river flows, and other conditions upstream of the dam. Sampling of fish in the juvenile bypass system (JBS) at Ice Harbor Dam has occurred from bi-weekly to every 3 to 4 days, which is less frequent than the daily sampling used at dams where fish are collected and held for transport. Less frequent sampling and a relatively high proportion of water spilled at this dam result in a small proportion of fish being collected. Therefore, collection counts reveal more about species composition than about run timing. Yearling Chinook salmon typically dominate the early part of the juvenile fish passage period, with the number of steelhead increasing toward middle and late spring (Figure 1.1). Second order polynomial fits are plotted to emphasize the general trends in relative abundance through the passage period. The percentages of subyearling Chinook salmon in the collection counts increase late in the spring and become dominant in the summer. Less abundant species, such as coho salmon and sockeye salmon only occasionally made up a notable proportion of a daily collection.

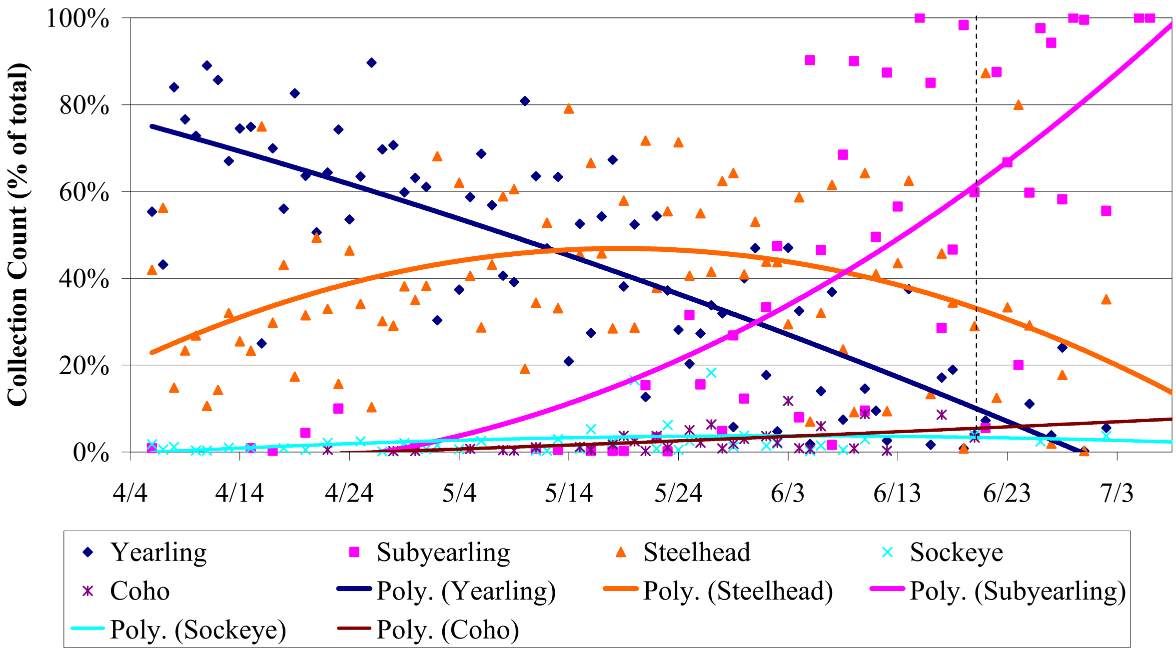

Figure 1.1. Trends in Species Composition at Ice Harbor Dam from 2000 Through 2006. Dashed vertical line indicates the nominal start of summer. Fits are second order polynomials. Data Source: Corps of Engineers, Walla Walla District.

1.3 Studies of Juvenile Fish Passage and Survival at Ice Harbor Dam from 1990 Through 2006

Table 1.1 lists the reports included in the current analysis. This set encompasses a variety of species, seasons, dam configurations, and fish passage conditions. These conditions were monitored using an array of study techniques to measure passage distributions, survival rates, injury rates, and migration timing. Table 1.2 indicates which reports address particular years and areas of study. Information from draft reports was not included. Information from draft reports was not included.

Table 1.1. Studies of Juvenile Fish Passage at Ice Harbor Dam, 1990–2006

Year	Study	Reference Number
1997	Eppard et al. 1998	1
1999	Eppard et al. 2000	2
1999	Ferguson et al. 2005	3
2000	Eppard et al. 2002	4
2001	Axel et al. 2003	5
2002	Eppard et al. 2005b	6
2003	Absolon et al. 2005	7
2003	Carlson and Duncan 2004	8
2003	Eppard et al. 2005c	9
2003	Moursund et al. 2004	10
2003	Normandeau Associates, Inc. 2004	11
2004	Axel et al. 2005	12
2004	Collis et al. 2006	13
2004	Eppard et al. 2005a	14
2004	Normandeau Associates, Inc. and Skalski 2005	15
2004	Ogden et al. 2005	16
2005	Axel et al. 2007a	17
2005	Moursund et al. 2007	18
2005	Normandeau Associates, Inc. 2006	19
2005	Ogden et al. 2007	20
2006	Axel et al. 2007b	21
2006	Ham et al. 2007	22
2006	Normandeau Associates, Inc. 2006	23
2006	Ogden et al. 2008	24
2000-2006	Faulkner et al. 2007	25
2004-2006	Carlson et al. 2008	26

Table 1.2. Matrix of Reports Including Biological Data for Ice Harbor Dam

	Focus Area	1997	1999	2000	2001	2002	2003	2004	2005	2006
Species	Yearling Chinook	1	2, 3	4, 25	5, 25	6, 25	7, 9, 10, 11, 25	13, 14, 15, 25	17, 18, 19, 25	21, 22, 23, 25
	Steelhead	–	3	25	25	25	10, 25	12, 13, 25	17, 18, 25	21, 22, 25
	Subyearling Chinook	1	3	4	–	6	7, 10, 11	13, 15, 16	18, 19, 20	23, 24
	Sockeye	–	–	–	–	–	–	13	–	–
Age Group	Juvenile	1	2, 3	4, 25	5, 25	6, 25	7, 9, 10, 11, 25	12, 13, 14, 15, 16, 25	17, 18, 19, 20, 25	21, 22, 23, 24, 25
	Adult	–	–	–	–	–	–	–	–	–
Methods	Hydroacoustic	–	–	–	–	–	10	–	18	22
	Radio telemetry	1	2, 3	4	5	6	9	12, 14, 16	17, 20	21, 24
	PIT Tagging	–	–	4, 25	5, 25	6, 25	7, 9, 25	12, 13, 14, 25	17, 25	21, 24, 25
	Sensor Fish	–	–	–	–	–	8	26	26	26
	Balloon Tagging	–	–	–	–	–	11	15	19	23
Dam Configuration & Spill Treatment Tests		–	–	4		6	7, 8, 9, 10, 11	12, 14, 15, 16, 26	17, 18, 19, 20, 26	21, 22, 23, 26
Dam Passage and Survival	Forebay Residence & Approach	–	–	–	5	–	9, 10	12, 14, 16	17, 20	21
	Dam Passage	1	2, 3	–	5	–	9	12, 14, 16	17, 18, 20	21, 22, 24
	Dam Survival	1	2	4	5	6	7, 9	12, 14, 16	17, 20	21, 24
	–	–	–	–	5	–	9	12, 14, 16	17, 20	21
Predation		–	–	25	5, 25	25	25	12, 13, 14, 16, 25	17, 25	21, 25
Direct Injury		–	–	–	–	–	8, 11	15, 26	19, 26	23, 26

PIT = passive integrated transponder
– = no studies.

1.4 Report Contents and Organization

The ensuing sections of this report briefly describe the fish passage situation at Ice Harbor Dam—dam features and configuration changes (Section 2.0) and river conditions and dam operations (Section 3.0) over time. The latter—including discharge, spill, total dissolved gas, water temperature and elevation, and turbidity—are described to show how environmental conditions, project capacities, and operational choices influence the routing of water through the dam and affect fish passage and survival. Discussion of the fish distribution and movement in the dam forebay follows in Section 4.0, which addresses forebay approach distributions, residence times, vertical distributions, and conclusions based on synthesis of biological research data over time. Juvenile salmonid passage is discussed in Section 5.0, including fish passage route distributions, project-wide passage metrics, the fish guidance efficiency of screens, passage through surface flow outlets, and related conclusions based on synthesis of the biological data. In Section 6.0, a discussion of juvenile salmonid survival addresses dam-wide and route-specific survival rates, predation, and related conclusions. Tailrace egress time, direct injury studies, and optimization of juvenile passage strategies at Ice Harbor Dam are discussed in Sections 7.0, 8.0, and 9.0, respectively. Supplemental information on treatment schedules for 2000 through 2006 is contained in Appendix A. Appendix B contains supplemental information about the relationship between discharge and downstream pool elevation and the tailrace water elevation at Ice Harbor Dam. Appendix C contains an annotated bibliography of studies at Ice Harbor Dam.

2.0 Overview of Ice Harbor Dam Features and Configurations

Ice Harbor Dam, located on the Snake River at river mile 9.7, is the first hydroelectric dam on the Lower Snake River upstream of its confluence with the Columbia River. The original dam project was authorized in 1945 by Section 2 of the River and Harbor Act (59 Stat.10 1945) and approved on March 2, 1945, in accordance with House Document 704, 75th Congress, 3rd Session. Construction of the dam began in December 1955 and project operations began in December 1961. The initial structure contained three turbine units; three additional units were added and operational by January 1976. Lake Sacajawea, the reservoir behind Ice Harbor Dam, extends 32 miles upstream to Lower Monumental Dam.

2.1 Major Dam Features

The dam structure at Ice Harbor, a concrete gravity type, is 2822 feet long, 100 feet high, and consists of a powerhouse containing six Kaplan-type turbine units, a 10-bay spillway, a navigation lock, two fish ladders, and an earth-filled section (Figure 2.1). A removable spillway weir (RSW)—a surface flow outlet intended to pass a high proportion of fish per proportion flow and result in a high survival rate—was added to spillbay 2 in 2005.

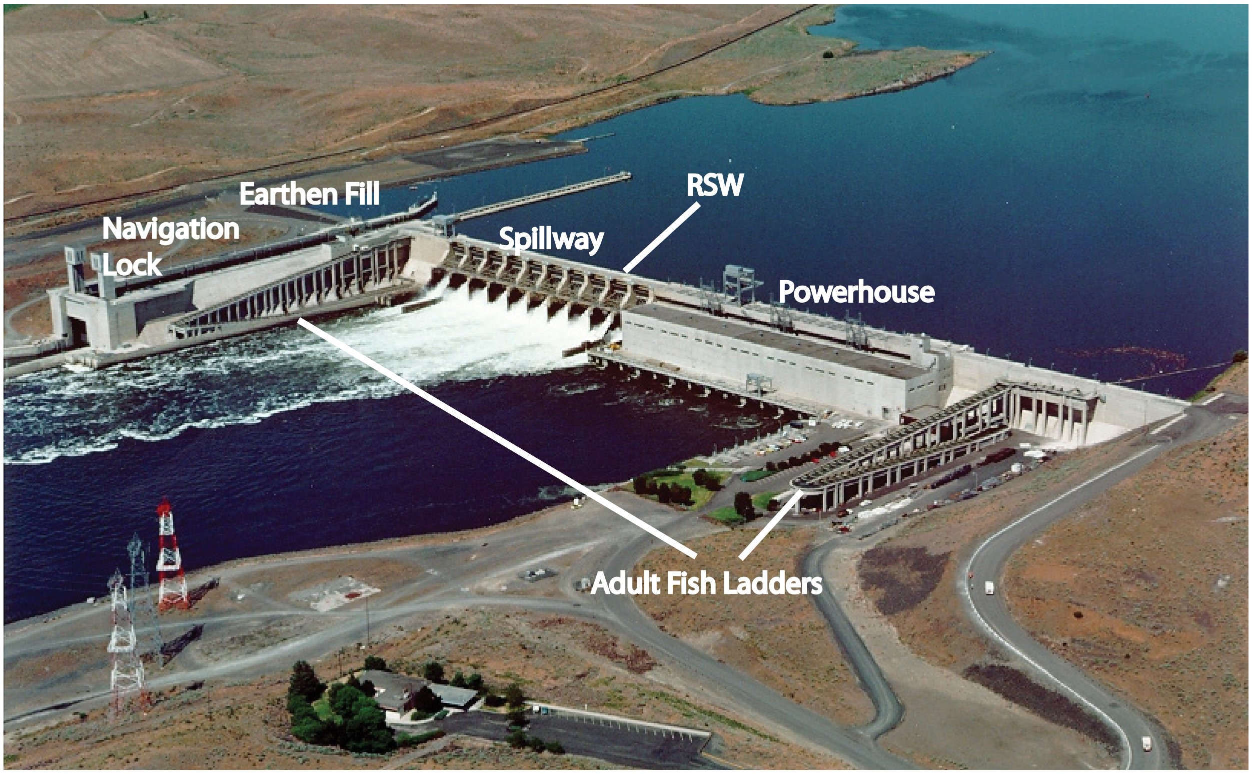

Figure 2.1. Major Features of Ice Harbor Dam. Photo source: U.S. Army Corps of Engineers, http://www.nww.usace.army.mil/dpn/dpn_project.asp?project_id=59 (Accessed on 2/6/2008).

2.1.1 Powerhouse

The Ice Harbor powerhouse is 671 feet long and contains three 90,000-kilowatt turbine units (1 through 3) and three 111,000-kilowatt turbine units (4 through 6). Turbine units are numbered from 1 (nearest the south bank) to 6 (nearest the spillway). All six turbines are Kaplan, six-blade units. Units 1 through 3 rotate at 90.0 revolutions per minute (rpm), while units 4 through 6 rotate at 85.7 rpm. Power generation through September 1994 was 73.81 billion kilowatt hours. Standard-length submersible traveling screens (STSs) are present in all turbine intake bays.

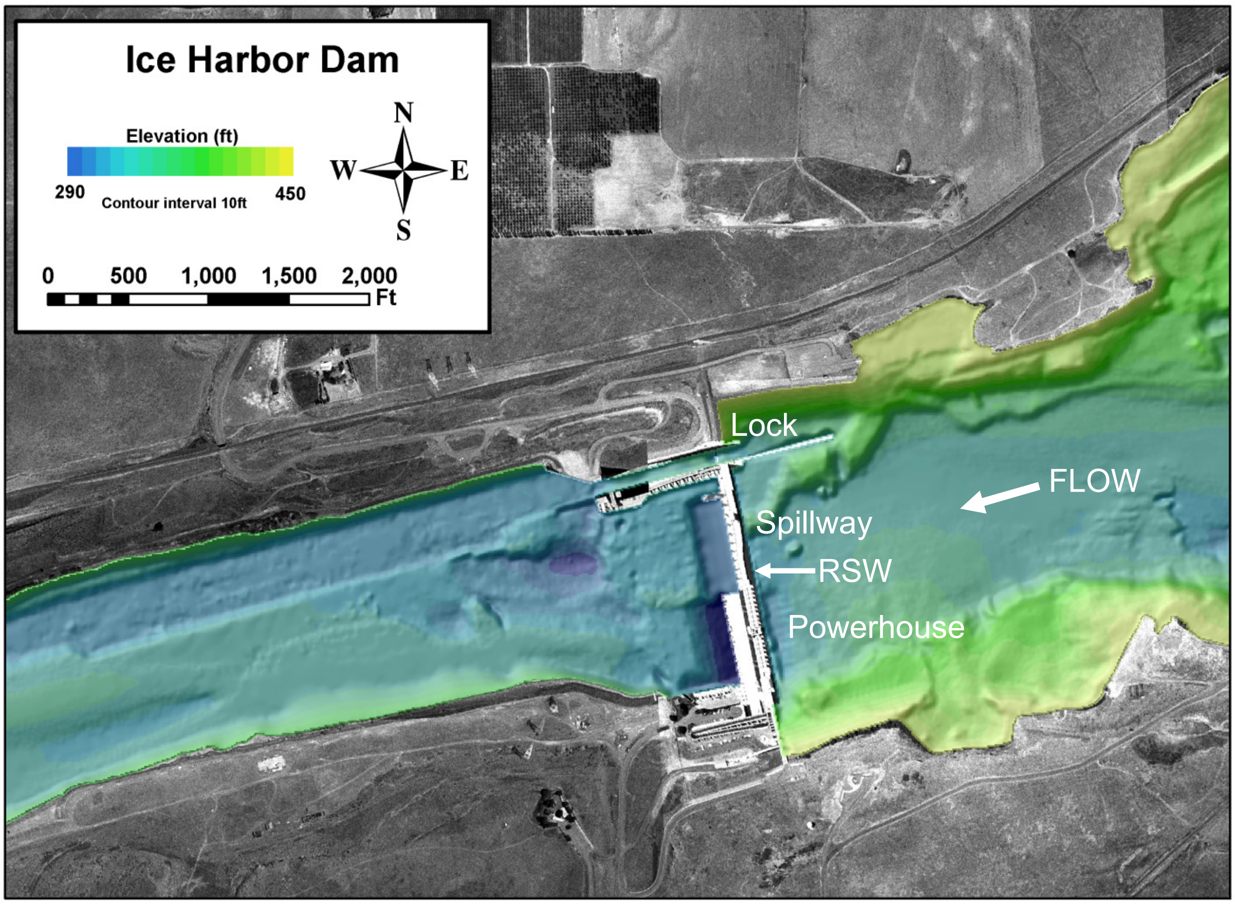

Figure 2.2. Plan View of Ice Harbor Dam Showing Bathymetry

2.1.2 Spillway

The spillway is 590 feet long, 139 feet wide at the base, and 141 feet high (from foundation to deck). It contains 10 bays with a crest elevation of 391 feet above msl and a gate seal elevation of 389 feet above msl. Spill is controlled by radial (Tainter-style) spill gates that are 50 feet wide by 53 feet high. Spill bays are numbered 1 through 10 from south (near the powerhouse) to north (near the navigation lock). A concrete-lined stilling basin extends 590 feet wide and 168 feet long with a floor elevation of 304 feet above msl downstream along the river bottom. The spillway has a peak flood discharge of 850,000 cubic feet per second (cfs).

To reduce total dissolved gas (TDG) supersaturation, deflectors (concrete sills) were installed at spillbays 1 through 10 over 3 years: 1996 (bays 2 through 5), 1997 (bays 6 through 9), and 1998 (bays 1 and 10). In 1996 and 1997, 15-foot radius deflectors were installed at an elevation of 338 feet above msl, and in 1998, 15-foot radius deflectors and divider walls were installed at an elevation of 334 feet above msl. The deflectors were designed to reduce TDG by causing spilled water to skim across the water surface rather than plunging to the bottom of the stilling basin.

The RSW installed in spillbay 2 in 2005 is 105 feet tall, 70 feet wide, and weighs 1.7 million pounds.[1] It is designed to provide a safe and attractive route of passage for juvenile fish.

2.1.3 Navigation Lock

The navigation lock is a single-lift lock that is 675 feet long by 86 feet wide, with a 16-foot minimum depth and a 103-feet maximum depth. The upstream gate is a radial type that is 25 feet high. The downstream gate is a vertical lift gate that is 91 feet tall. Although a small proportion of juvenile migrants pass through the lock, its operation is not managed for juvenile fish passage.

2.1.4 Fish Passage Facilities

Facilities for juvenile fish passage consist of standard-length STSs, vertical barrier screens in the gatewells, two 1-foot diameter gatewell orifices, collection channel and dewatering structures, sampling facilities, and a bypass flume/pipe that transports fish to the sampling facilities and the tailrace below the dam. In April 2005, passive integrated transponder (PIT)-tag detectors were activated in the full flow segment of the JBS just downstream of the primary dewatering system.

There are two adult fish passage facilities, one on the north shore and the other on the south shore. The facility on the north shore has a fish ladder, a small collection system, and an auxiliary water supply system. The south-shore facilities contain a fish ladder, a powerhouse collection system, and an auxiliary water supply system.

2.2 Ice Harbor Dam Configuration Changes

Major Ice Harbor Dam improvements from 1990 through 2006 are listed in Table 2.1. Between 2000 and 2006 two major improvements were completed: a full-flow bypass PIT-tag system and the RSW. The PIT-tag system, which was completed in April 2005 (Downing and Axel 2007), allows detection of PIT tags in fish as they are returned to the river downstream, and it does not require that fish be collected for examination and tag detection. The RSW installation was completed before the spring juvenile salmonid migration period of 2005. RSW fish passage and survival performance was compared with a bulk spill treatment during which the RSW was not operational (Axel et al. 2007a; Moursund et al. 2007; Ogden et al. 2007). More recent operations have combined both bulk spill and RSW concepts.

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[1] http://www.nww.usace.army.mil/spillway_weir/SW_FctShtMay05.pdf (Accessed on 2/6/2008)

Table 2.1. Fish Passage Improvements at Ice Harbor Dam

Year	Juvenile Passage Improvements	Purpose
1996	Powerhouse bypass system consisting of submerged traveling screens (STSs) and vertical barrier screens (VBSs) put in each turbine intake, 1-ft orifices drilled from gatewell to bypass channel in old sluiceway, evaluation/marking facilities at bottom of bypass flume to carry juveniles to the tailrace.	Increase the percentage of fish diverted from turbine passage
1996	Four deflectors installed at spillbays 2, 3, 4, and 5; 338 ft above msl and 15-ft radius	Reduce TDG levels
1997	Four deflectors installed at spillbays 6, 7, 8, and 9; 338 ft above msl and 15-ft radius	Reduce TDG levels
1998	Two deflectors installed at spillbays 1 and 10; 334 ft above msl and 15-ft radius and divider walls	Reduce TDG levels
2005	PIT-tag detection on main bypass flume implemented on April 19	Allow PIT-tag monitoring with lower potential for stress
2005	RSW installed at spillbay 2	Reduce passage at powerhouse, reduce delay in the forebay

3.0 River Conditions and Dam Operations

Project operations distribute the discharge of river water to the different passage routes at dams. This distribution of flow strongly influences the routes used by fish passing through the dams, which influences their probability of survival. It is important to understand how environmental conditions, project capacities, and project operational choices influence the routing of water through the dam. Annual trends in river discharge, spill levels and patterns, water temperature, and TDG levels at Ice Harbor Dam for 1990 through 2006 are described below.

3.1 River Discharge

River discharge at Ice Harbor Dam varied from year to year and between the spring and summer passage seasons (Figure 3.1). Discharge levels during the summer passage period were typically much lower than during the spring passage period. A high flow year, such as 1997, had more than double the median flow of a low flow year, such as 2001, in either spring or summer. Upstream storage reservoirs provide a limited ability to moderate extremes of discharge within a season, but variation due to weather is very evident in the series of annual discharge levels. As a result of this large variation among years, fisheries managers must be prepared to provide safe passage conditions over a wide variety of dam operations. In addition, dam configurations must provide good fish passage conditions across the variety of operations. Fish passage plans have long acknowledged the need for various passage strategies in response to different river conditions. An ideal passage plan would specify a suite of operations that meets performance goals at each discharge level and a configuration that is flexible enough to support the operations and varying passage strategies.

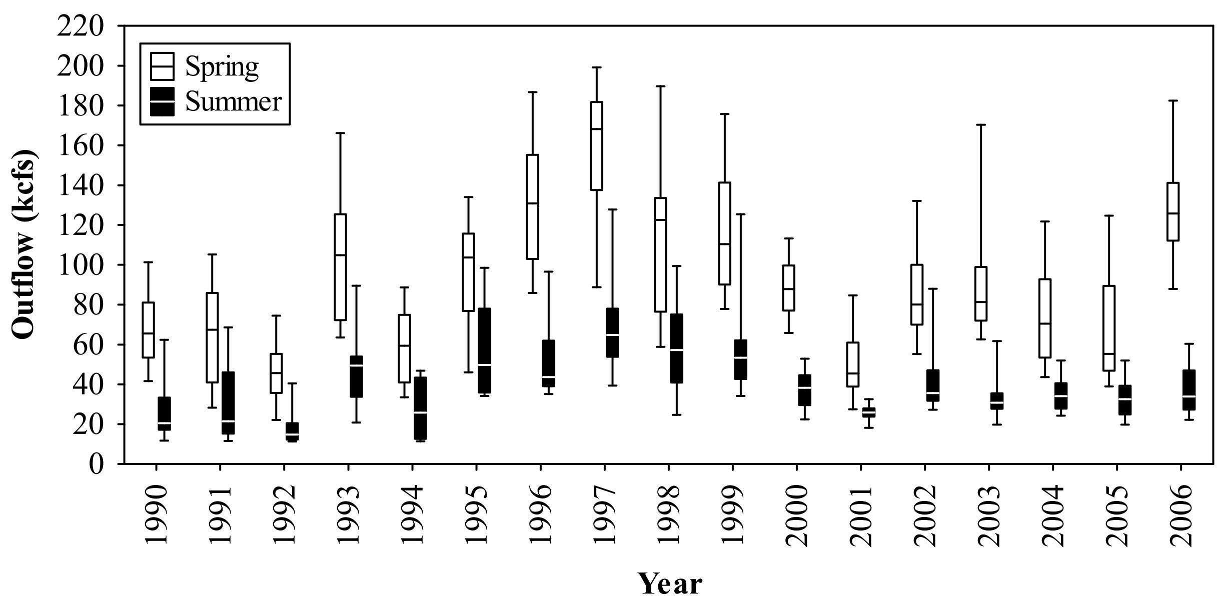

Figure 3.1. Median Daily River Discharge by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile. Source: Northwest Division, U.S. Army Corps of Engineers.

3.2 Spill

Water passed over the spillway is referred to as "spill." River discharge in excess of powerhouse capacity (approximately 100 thousand cubic feet per second [kcfs]) must be spilled, whether or not spill is planned. At levels of river discharge below powerhouse capacity, voluntary spill has been used to increase the proportion of fish to pass over the spillway instead of through the powerhouse. The level of spill also can be modified to achieve desired fish passage conditions in the tailrace of the dam. Thus, the volume and proportion of water spilled are a function of the total river discharge and the operational choices made at the dam.

At Ice Harbor Dam, fish passage plans have specified spill amounts in terms of either volume (i.e., 45 kcfs) or proportion of total spill (i.e., 30%). Annual means can vary from those amounts due to high or low flows that prevent operating the dam at the specified spill level. Figure 3.2 illustrates the mean spill volume and spill proportion for the years 1990 through 2006. Note that summer spill volume is generally much lower than spring spill volume, but it often represents a greater proportion of total discharge.

3.2.1 Experimental Treatments

Recent experimental treatments tested at Ice Harbor Dam contrasted spill level, spill pattern, dam structures (RSWs), or combinations of those factors. Table 3.1 lists the treatments implemented at Ice Harbor Dam from 1990 through 2006 for each season. At Ice Harbor Dam, the principal configuration changes affecting juvenile salmonid passage and survival were the construction of the JBS in 1996 and the implementation of the RSW at spillbay 2 in 2005. The spill level for fish passage at Ice Harbor Dam has typically been specified as a discharge rate independent of total river discharge. For example, the 2000 Biological Opinion (BiOp) spill specified an instantaneous spill level of 100 kcfs (120% TDG limit) during the nighttime and 45 kcfs during the daytime. A lower proportion of spill, 30% in 2006, was tested in association with the RSW, because surface passage routes have often been found to attract more fish per unit of water spilled. The treatment conditions for each year are listed in Table 3.1.

3.2.2 Typical Spill Operations

The possible range of operations at Ice Harbor Dam is broad relative to other Snake River dams. Many dams require a minimum generation level to support the operation of the dam itself, but hourly operations data reveal times when no turbine units were generating power at Ice Harbor Dam. Minimum spill can be zero until total discharge exceeds powerhouse capacity. Conversely, all water can be spilled up to a level where the TDG in the tailrace exceeds water quality criteria. Spill in excess of this gas cap can occur when powerhouse capacity is insufficient to avoid spilling more than the specified amount.

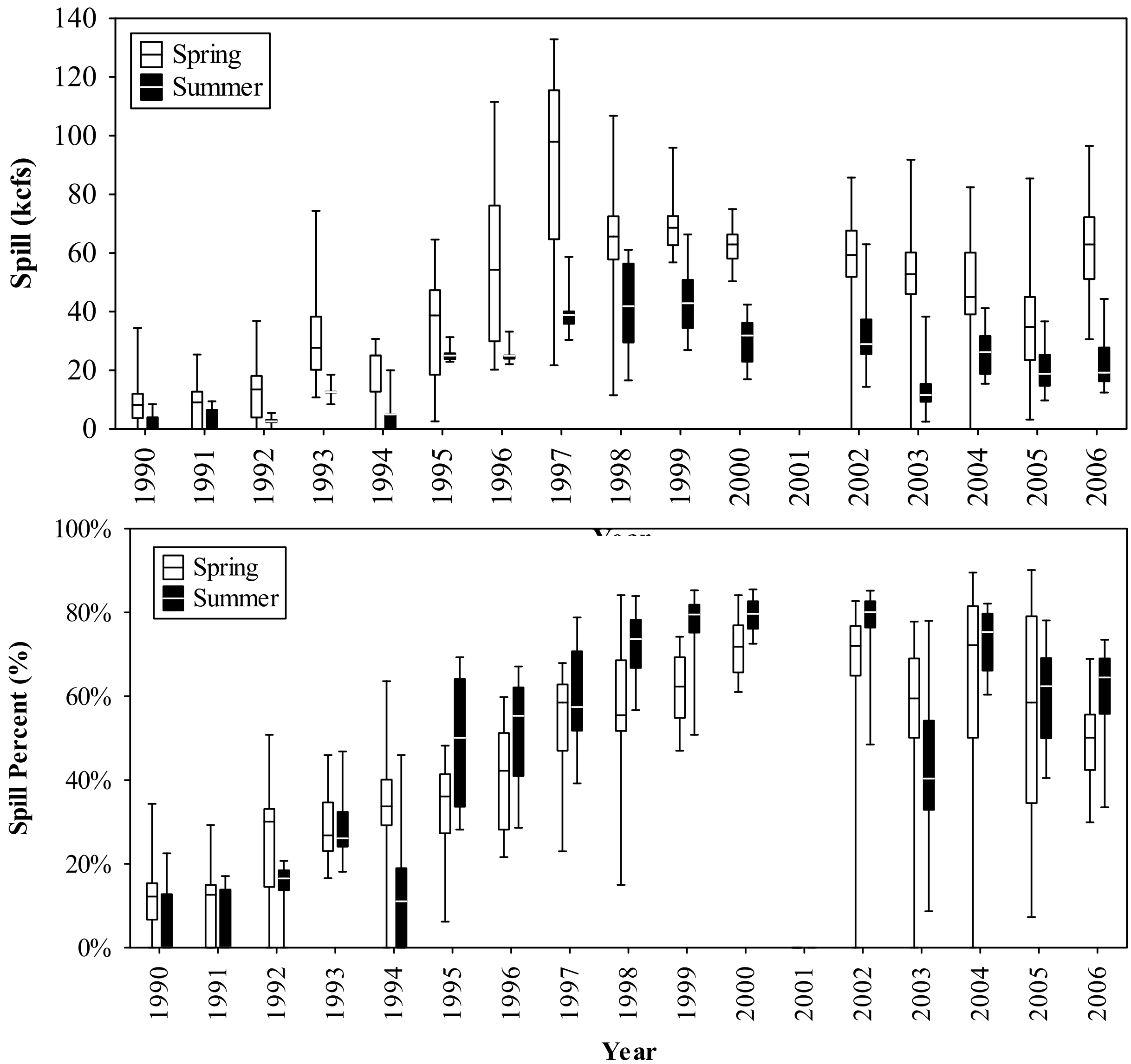

Figure 3.2. Median Daily Spill Volume (top) and Spill Proportion (bottom) by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile. Source: Northwest Division, U.S. Army Corps of Engineers.

Table 3.1. Dam Operations Implemented During Juvenile Fish Passage at Ice Harbor Dam from 1990 Through 2006

Year	Spill Treatment	Season	Spill Levels	Configuration
1988	1988 Spill Agreement	Spring	Zero spill day/25% night	No Change
		Summer	Zero spill day/25% night	No Change
1994	BiOp Spill	Spring	Zero spill day/60% night, up to 25 kcfs gas cap	No Change
		Summer	Zero spill day/30% night, up to 25 kcfs gas cap	No Change
1995	BiOp Spill	Spring	27%, 25 kcfs gas cap	No Change
		Summer	70%, 25 kcfs gas cap	No Change
1998	BiOp Spill	Spring	45 kcfs day/gas cap night (75 kcfs)	No Change
		Summer	45 kcfs day/gas cap night (75 kcfs)	No Change
2000	BiOp Spill	Both	45 kcfs day/gas cap night	No Change
2001	Zero Spill	Both	Zero spill	No Change
	May 19 Spill	Both	9.8 kcfs (0500 to 1100 PST)	No Change
2002	BiOp Spill	Both	45 kcfs day/gas cap night	No Change
2003	BiOp Spill	Both	45 kcfs day/gas cap night	No Change
	50% Spill	Both	50%	No Change
	Bulk Spill	Summer	45 kcfs, 6-stop min. spillgate opening	No Change
	Zero Spill	Summer	Zero spill	No Change
2004	Bulk Spill	Both	Gas cap, 6-stop min. spillgate opening,	No Change
	Flat Spill	Both	45 kcfs, 3-stop max. spillgate opening	No Change
2005	Bulk BiOp Spill	Both	45 kcfs day/gas cap night, 5-stop min. spillgate opening	RSW nonoperational
	RSW Spill	Both	30%, 5-stop min. spillgate opening	RSW operational
2006	BiOp Spill	Both	45 kcfs day/gas cap night, 5-stop min. spillgate opening	RSW operational
	30% Spill	Spring	30%, 5-stop min. spillgate opening	RSW operational

The ability to choose operations that influence fish passage is greatest at moderate total discharge levels when powerhouse capacity is sufficient to allow diverse operational possibilities. Numerous spill operations have been implemented from 1990 through 2006. Since 1998, typical spill levels at Ice Harbor Dam during the juvenile fish passage season (April 1 through October 31) have been 45 kcfs between 0500 and 1800 hours (day) and spill up to approximately 120% of saturation for TDG levels (roughly 100 kcfs) between 1800 and 0500 hours (night). Water quality standards restrict TDG to 110% of saturation, but waivers are in effect to allow up to 120% of saturation to allow greater spill for fish passage. Gas cap spill refers to the volume of water that is expected to achieve levels allowed by TDG waivers, specifically, the 120% tailrace TDG criterion, and the downstream forebay 115% TDG criterion.

In the years prior to 1998, the proportion of spill defined as the gas cap was lower because the full complement of spill deflectors was not yet installed. Alternative spill levels and patterns were tested from 2003 through 2006 as part of an ongoing program to optimize passage conditions and survival. The results of these tests are discussed in the subsequent sections, which provide data from studies on fish passage and survival.

Table 3.1 above indicates the planned operations for the fish passage seasons. The actual operations are summarized in Figure 3.3 and Figure 3.4 below for spring and summer, respectively. Figure 3.3 illustrates the frequency of occurrence of hourly combinations of spill and total flows for the spring passage period during the years 1990–2006. Colored lines indicate idealized operations for various spill treatments across a range of total flow. The size of the symbols on the plot indicates the relative frequency of occurrence of a combination of spill and total flow. Hours without spill were censored from the plot to allow a clearer view of the relative frequency of varying spill operations. The densest region in the daytime (upper panel) reflects operations at 45 kcfs. Much less dense, but still evident is a region reflecting 30% spill or 50% spill operations. The densest region in the nighttime (lower panel) reflects spill to the gas cap, and there is a less dense region reflecting 30% or 50% spill operations.

The frequency of occurrence of hourly combinations of spill and total flows for the summer passage period during the years 1990–2006 is illustrated in Figure 3.4. The densest regions for both day and night indicate that a large proportion of total flow was spilled and also that spill rarely exceeded the designated gas cap flow level during the summer. The lack of symbols on the leftmost slanted line during daytime suggests that it was rare to have no powerhouse units operating. At night, numerous symbols on that line suggest that it was not uncommon to have no powerhouse units in operation.

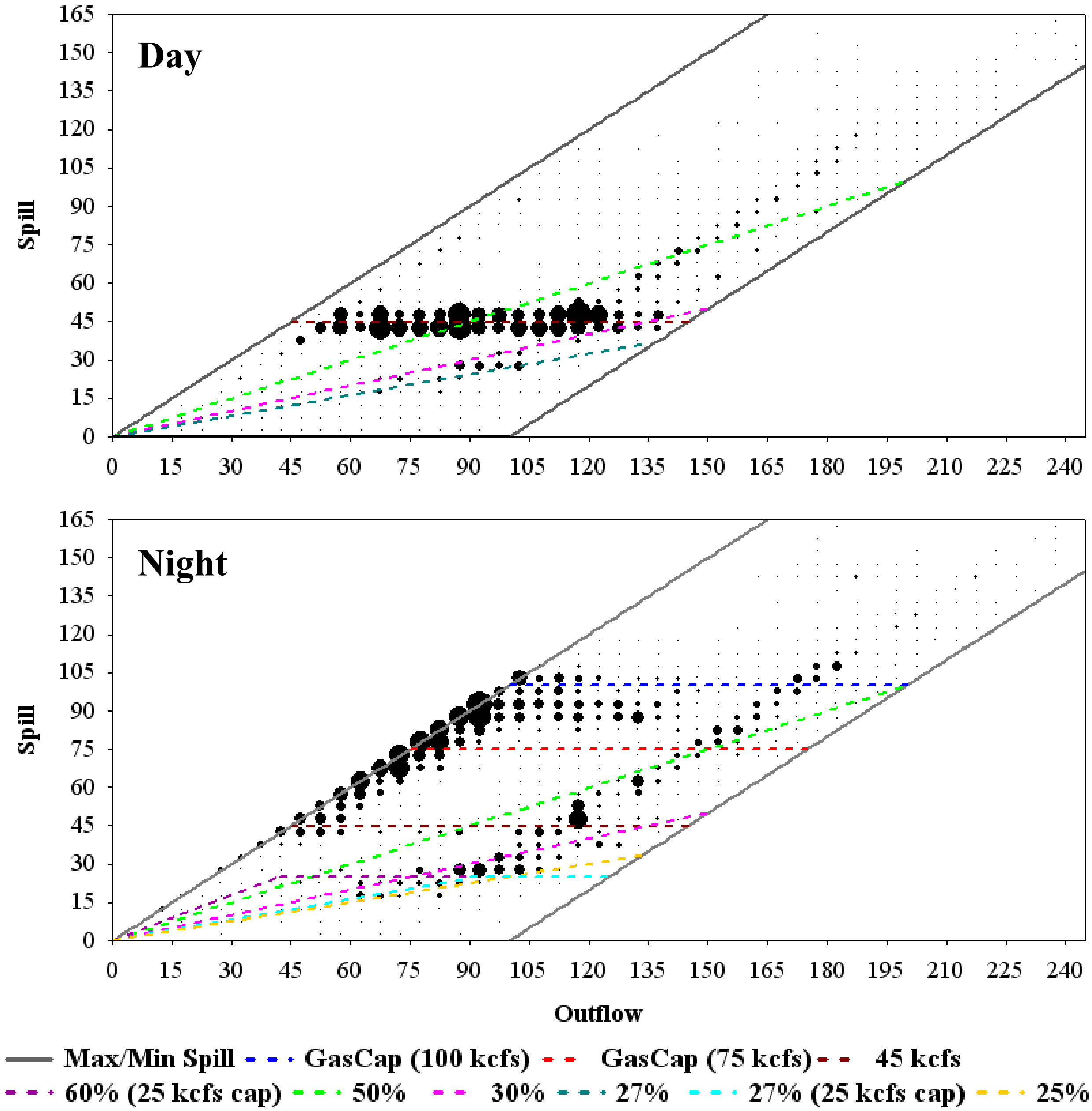

Figure 3.3. Frequency of Occurrence of Spill Versus Outflow During the Day (top) and Night (bottom) for the Spring Seasons of the Years 1990 Through 2006. Symbol size increases with the frequency of occurrence. Source: http://www.cbr.washington.edu/dart/river.html.

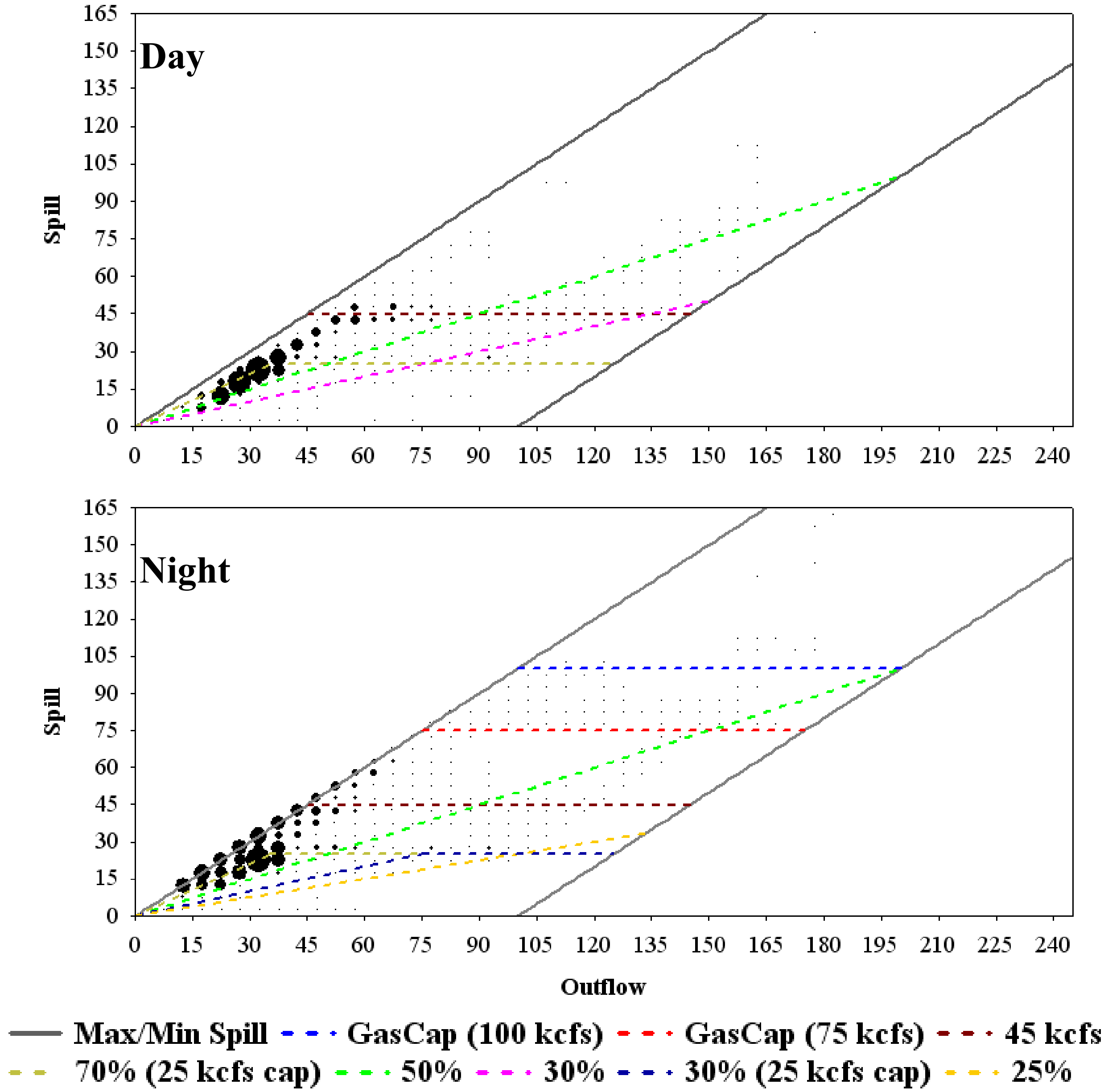

Figure 3.4. Frequency of Occurrence of Spill Versus Outflow During the Day (top) and Night (bottom) for the Summer Seasons of the Years 1990 Through 2006. Symbol size increases with the frequency of occurrence. Source: http://www.cbr.washington.edu/dart/river.html.

3.2.3 Spill Patterns

The typical spill pattern at Ice Harbor Dam prior to 2004 had been to distribute spill nearly uniformly among all of the spillbays, with smaller gate openings at the outer bays to maintain good conditions at adult ladder entrances (Figure 3.5, left panel). The 2004 test marked the beginning of evaluations of bulk spill patterns that impose minimum spill gate openings (Figure 3.5, right panel). Spill patterns in later years continued to develop the bulk spill approach and were adjusted to incorporate the RSW in spillbay 2.

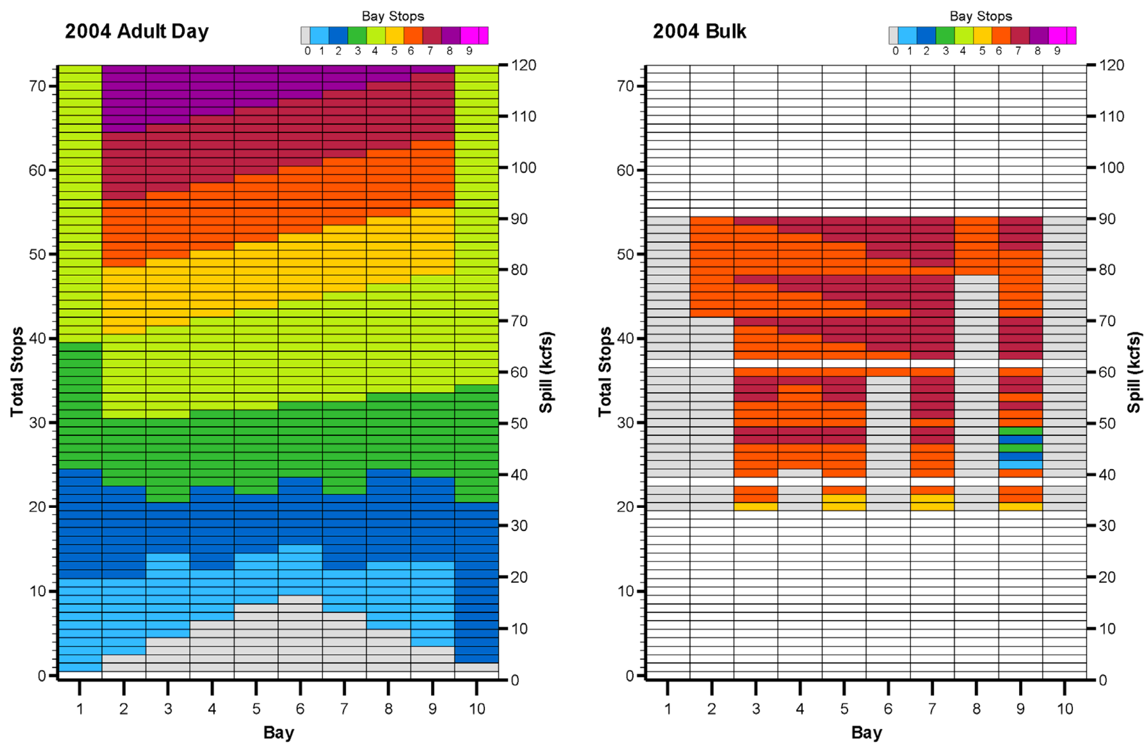

Figure 3.5. Uniform (left) and Bulk (right) Spill Patterns Implemented in 2004 at Ice Harbor Dam

3.3 Total Dissolved Gas

Total dissolved gas levels are monitored in the forebay and tailrace at Ice Harbor Dam. Forebay TDG values typically increase with high spill discharge at upstream dams. Tailrace TDG typically increases with increasing spill discharge at Ice Harbor Dam. Water quality standards limit the maximum TDG that can be generated downstream to 110% of saturation. Waivers are in effect to allow up to 120% of saturation at the tailrace monitor and 115% at the forebay monitor of the next dam downstream to allow more spill for fish. During the study years covered in this report, typical nighttime operations during the juvenile fish passage season at Ice Harbor Dam were to spill the maximum amount of water up to the TDG limits, referred to as gas cap spill.

3.3.1 Forebay Total Dissolved Gas

Inter-annual trends in forebay TDG for years 1990 through 2006 are illustrated in Figure 3.6. In general, forebay TDG levels were higher in the spring than in the summer because of higher flows and greater spill at upstream dams. In 2005, relatively low flows during the spring resulted in below-average values for forebay TDG. Higher-than-average summer TDG values reflect the fact that 2005 was the first year of court-ordered spill during the summer.

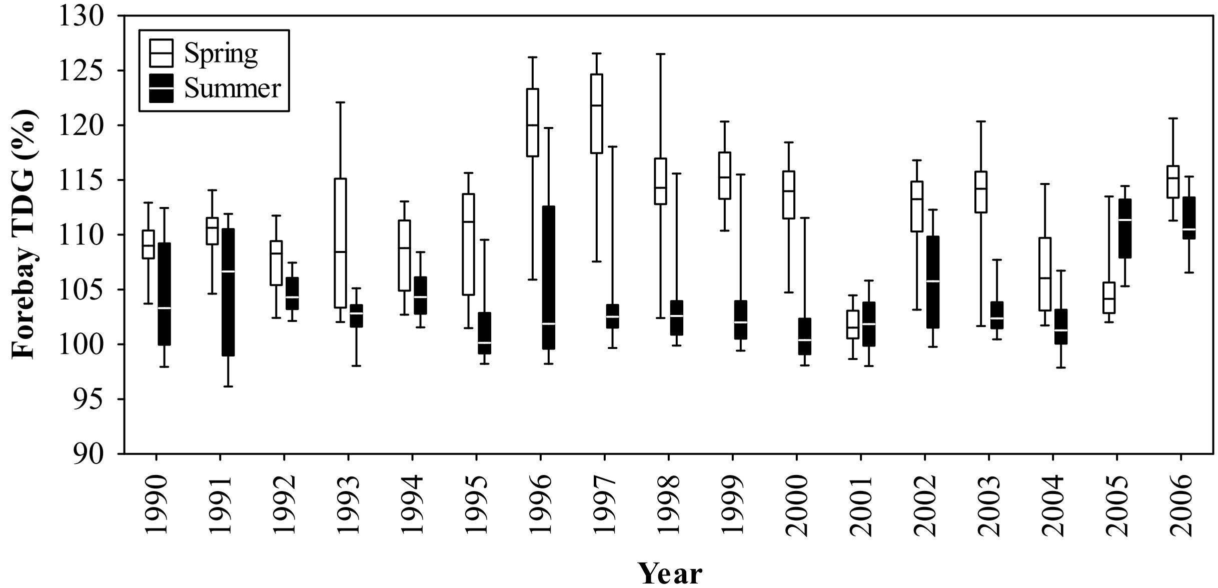

Figure 3.6. Median Daily Forebay Total Dissolved Gas Levels by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile.
Source: http://www.cbr.washington.edu/dart/river.html**.**

3.3.2 Tailrace Total Dissolved Gas

Tailrace TDG levels at Ice Harbor Dam are primarily dependent upon spill discharge at the dam. Figure 3.7 shows the inter-annual trend in tailrace TDG values for the years 1994 through 2006. Data were not available for 1990 through 1994. Median daily tailrace TDG levels exceeded 120% during the high flow years of 1996 and 1997. The zero spill operations during the low flow year of 2001 resulted in tailrace TDG levels well below the 110% saturation level.

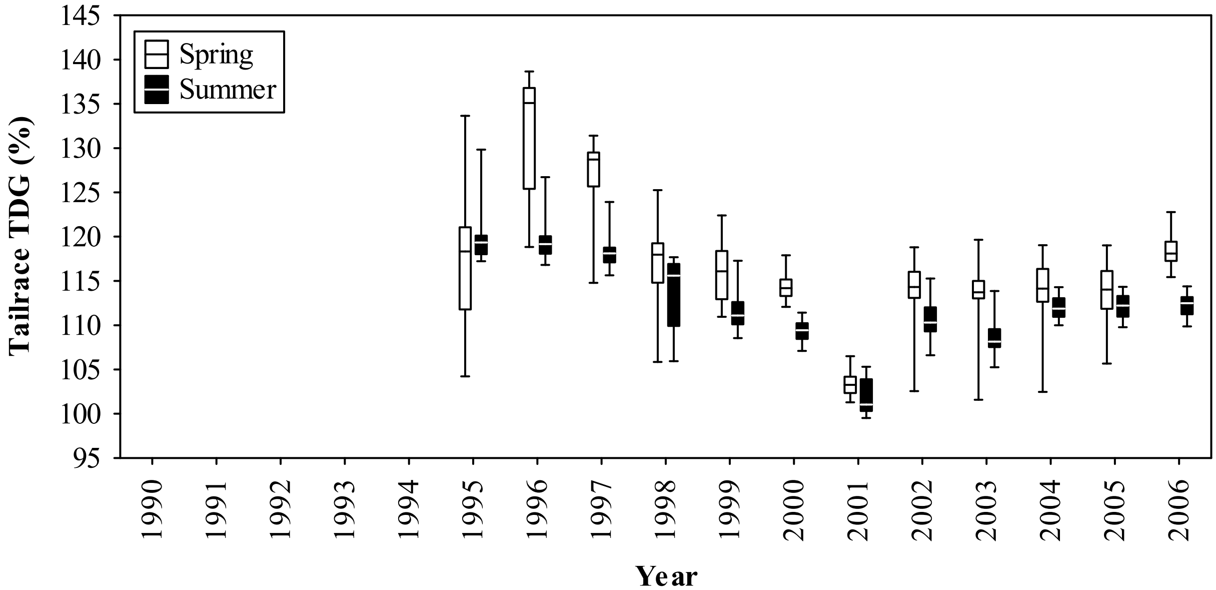

Figure 3.7. Median Daily Tailrace Total Dissolved Gas Levels by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile. Data not available for 1990-1994. Source: http://www.cbr.washington.edu/dart/river.html.

3.4 Water Temperature

The most complete series of water temperature data was that for the scroll case temperature (Figure 3.8). Measurements of temperature at water quality monitoring stations might provide a better indication of temperatures experienced by fish, but were not available for earlier years of interest in this analysis. Median daily scroll case temperatures varied between seasons, but each season varied only about 3.5 °C from highest to lowest average temperatures among years.

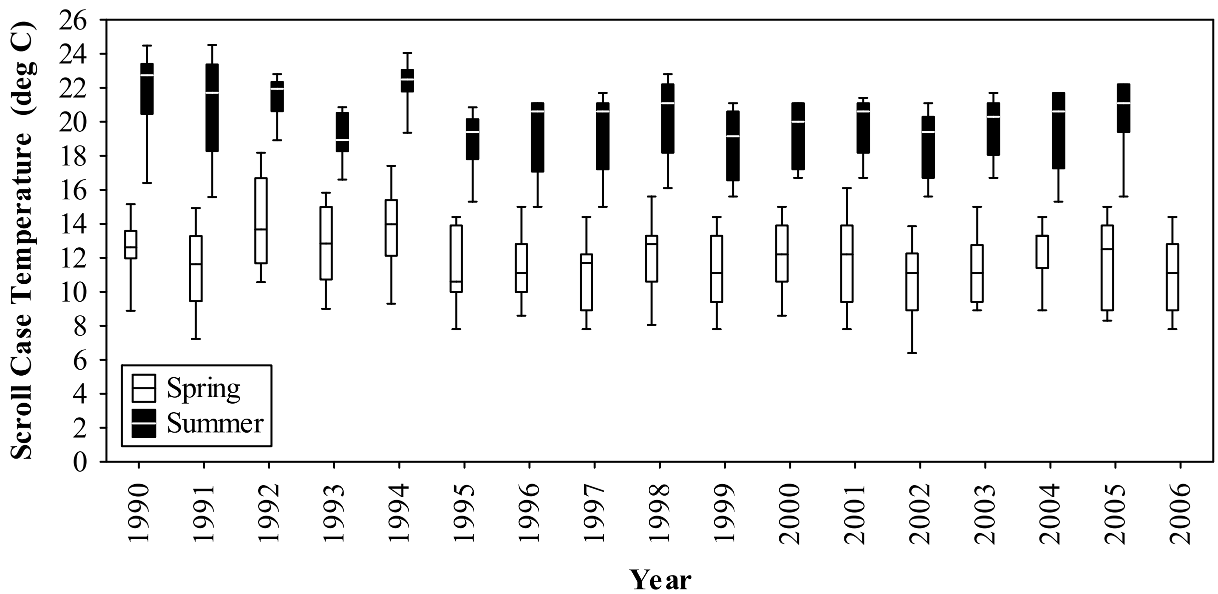

Figure 3.8. Median Daily Scroll Case Temperature by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile. Source: http://www.cbr.washington.edu/dart/river.html.

3.5 Water Elevation

Water elevations in the forebay vary with the filling and emptying of Ice Harbor Reservoir, which depends upon the operations at Ice Harbor Dam and upon water entering the reservoir from Lower Monumental Dam upstream. Tailrace elevations vary with operations at Ice Harbor Dam and with the level of the McNary Dam pool, which backs up to the tailrace at Ice Harbor Dam.

3.5.1 Forebay Elevation

The normal operating pool at Ice Harbor Dam is 440 feet above msl. Ice Harbor Dam is currently operated at a minimum operating pool (MOP) elevation of 437 feet above msl) with fluctuations up to 438 feet from April through August. However, from 2001 through 2005 it was necessary to operate at MOP +1 (438–439 ft) to maintain authorized channel depth because court injunctions had blocked maintenance dredging (Figure 3.9). The mean forebay elevations prior to 1999 were frequently higher and more variable.

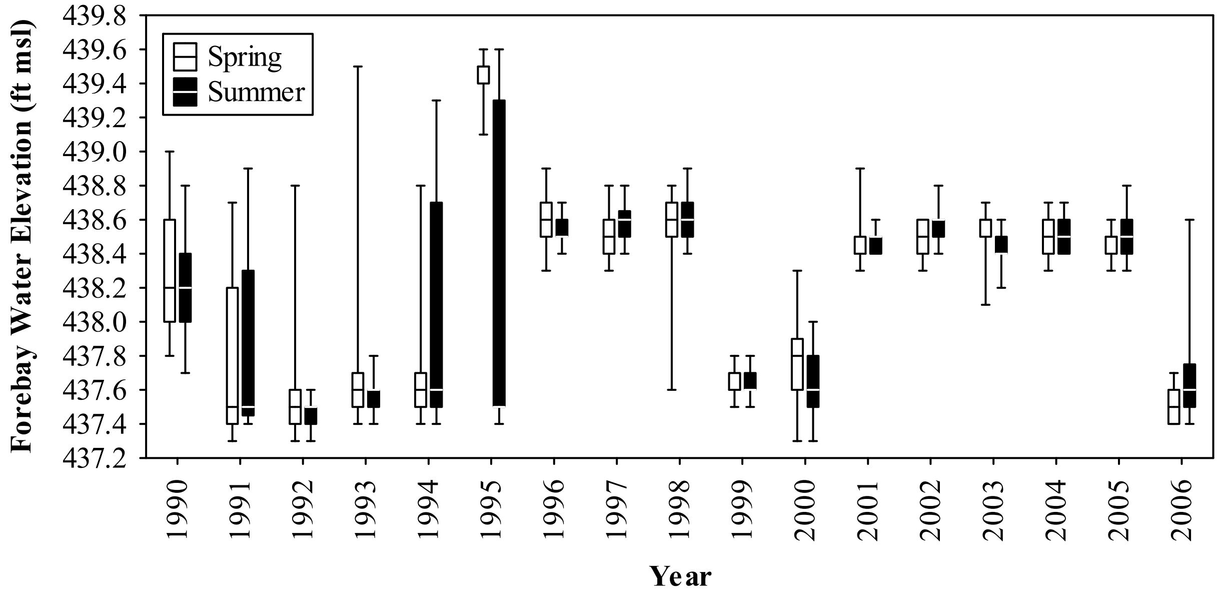

Figure 3.9. Median Daily Forebay Water Elevation by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile.
Source: http://www.cbr.washington.edu/dart/river.html.

3.5.2 Tailrace Water Elevation

Tailrace water elevation at Ice Harbor Dam is dependent on river discharge and the elevation of McNary Dam pool. High flows in the spring of 1996 and 1997 resulted in the highest median tailrace water elevations (Figure 3.10). Higher spring flows resulted in higher median tailrace water elevations. The tailrace water elevation during 2001 was near the low end of the range of annual medians for the years 1990 through 2006. Rating curves for estimating tailrace water elevations as a function of Ice Harbor Dam discharge and pool elevation above McNary Dam were provided by the Walla Walla District and can be viewed in Appendix B, Figure B.1.

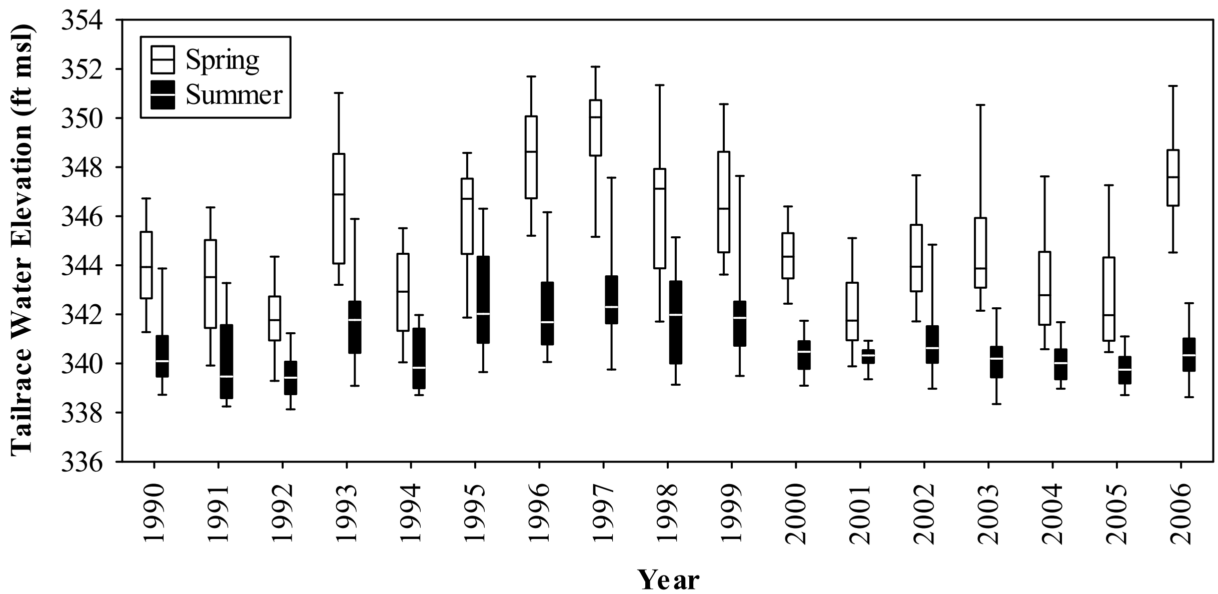

Figure 3.10. Median Daily Tailrace Water Elevation by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile.
Source: http://www.cbr.washington.edu/dart/river.html.

3.6 Turbidity

Secchi depth (the depth at which a specially marked disk becomes obscured) provides a measure of water clarity. As water clarity increases, Secchi depth increases and turbidity decreases. Median Secchi depths from 1990 through 2006 varied widely among years and seasons (Figure 3.11). Low flow years, such as 2001, were associated with higher Secchi depths, whereas high flow years, such as 1997, were associated with low Secchi depths.

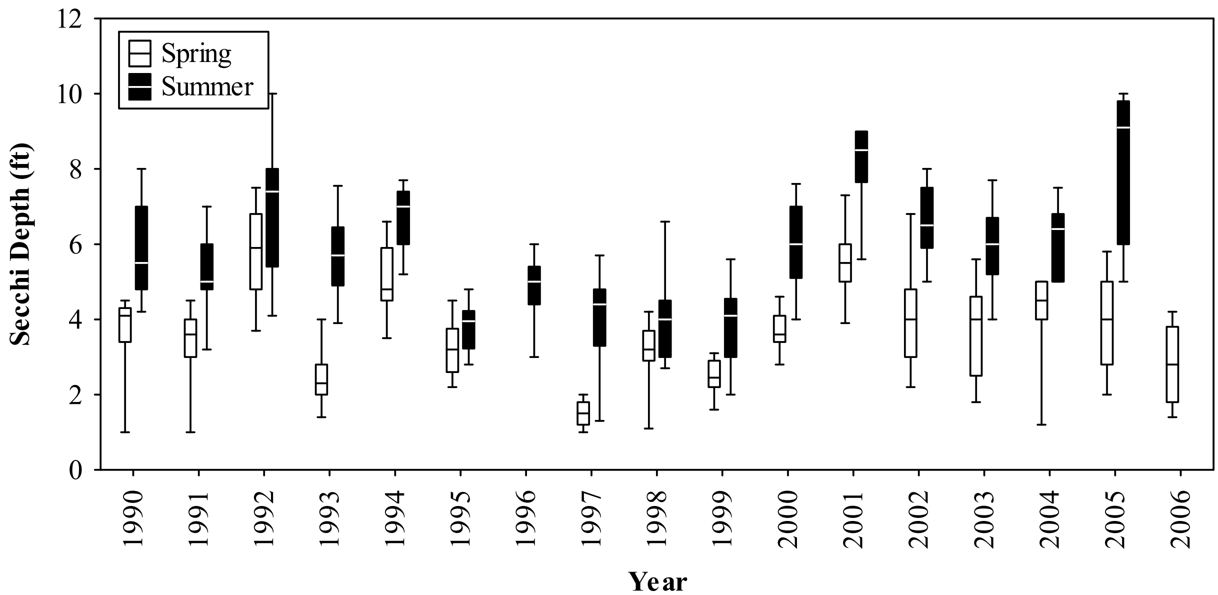

Figure 3.11. Median Daily Secchi Depth by Year and Season at Ice Harbor Dam. The horizontal line indicates the median. Boxes include the middle 50%. Bars include the range from the 5th to the 95th percentile. Source: Northwest Division, U.S. Army Corps of Engineers.

4.0 Fish Distribution and Movement in the Forebay

If operations or configurations can alter how fish approach the dam, it may be possible to influence where fish pass, how long it takes to approach and pass, and possibly reduce the rate of mortality in the forebay. To this end, this section describes the forebay approaches, residence times, vertical distributions, and synthesis of fish distribution and movement in the forebay at Ice Harbor Dam relative to treatments and configurations.

4.1 Forebay Approach Distributions

Forebay approach distributions at Ice Harbor Dam have been compared at radio-telemetry detection zones upstream of the dam and at radio-telemetry and hydroacoustic detection zones at the face of the dam. The results of several years of study suggest that spill proportion and spill pattern affect the distribution of fish approaching Ice Harbor Dam.

In 2003, the BiOp spill operation (45 kcfs spill during the day and spill to the gas cap at night) was compared with a 50% spill operation. Differences between these treatments were small during the day, but much larger at night. Although no differences were noted in the upstream forebay distributions, a higher proportion yearling Chinook salmon entering during BiOp spill were detected approaching the spillbays relative to 50% spill conditions (Figure 4.1).

Subyearling Chinook salmon approaching the dam under bulk spill conditions, when a high volume of water was released from a limited number of spillbays, had a higher probability of being detected upstream of the spillway and a lower probability of approaching the powerhouse than under flat spill conditions when a lower spill volume was equally distributed among all spillbays (Figure 4.2). Unfortunately, the treatments in this test of bulk spill differed not only in the pattern of spill, but also in the proportion of total discharge that was spilled. This simultaneous variation of two operational factors makes it impossible to identify which factor was influencing forebay distributions.

In 2005, a bulk spill treatment was contrasted with an RSW spill treatment. These treatments differed in both the amount of spill and in the configuration of the dam (whether or not the RSW was operated). During the RSW treatment, spill proportion was approximately half that of the bulk spill treatment. During the RSW treatment, 11% fewer yearling Chinook salmon approached the spillway (Figure 4.3). The multiple differences among treatments make it difficult to determine whether spill proportion or RSW operation was most influential on forebay approach distributions.

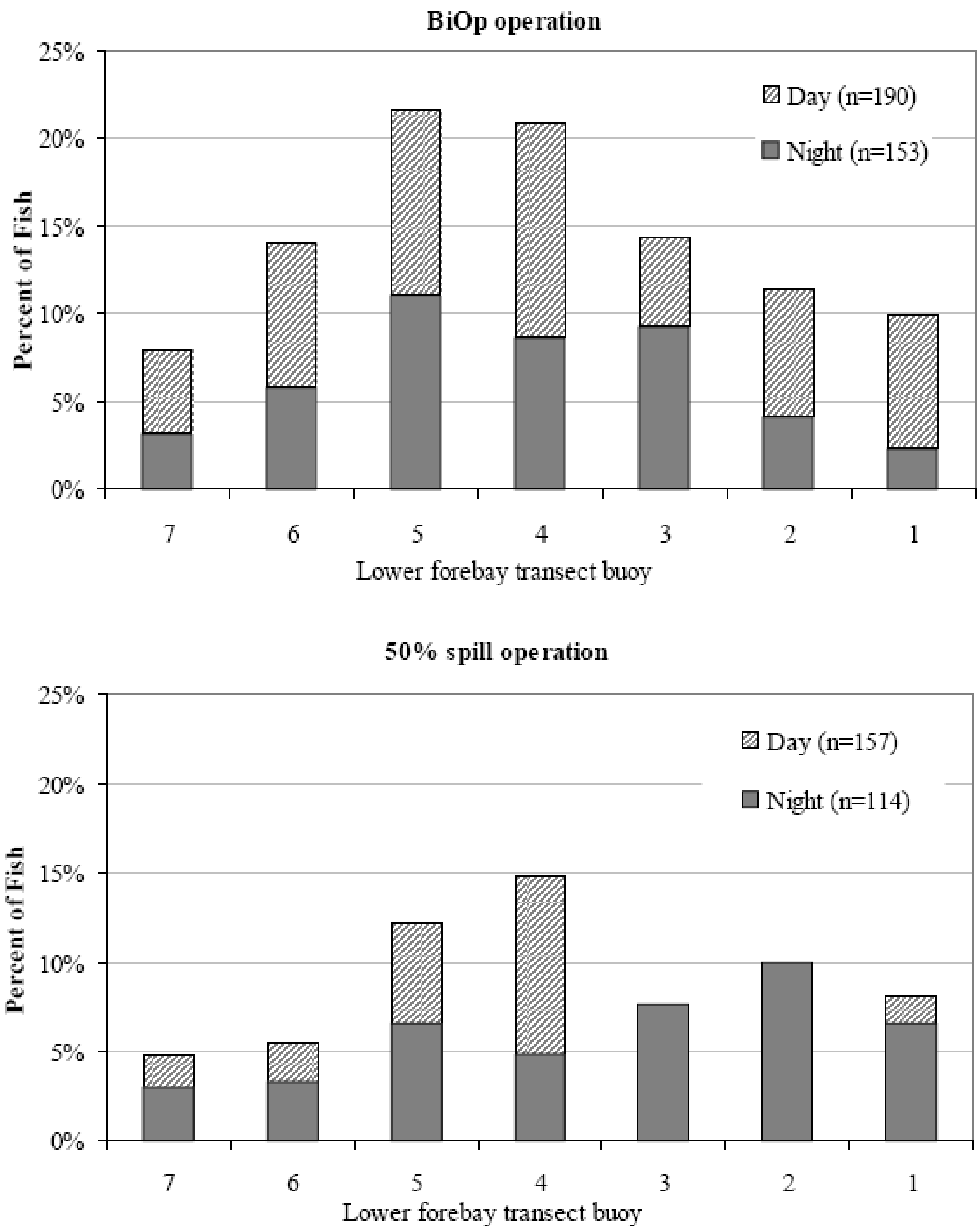

Figure 4.1. Forebay Approach During BiOp and 50% Spill Treatments and Spillway and Turbine Passage for Yearling Chinook in 2003 at Ice Harbor Dam. Source: Eppard et al. 2005c, Figure 8.

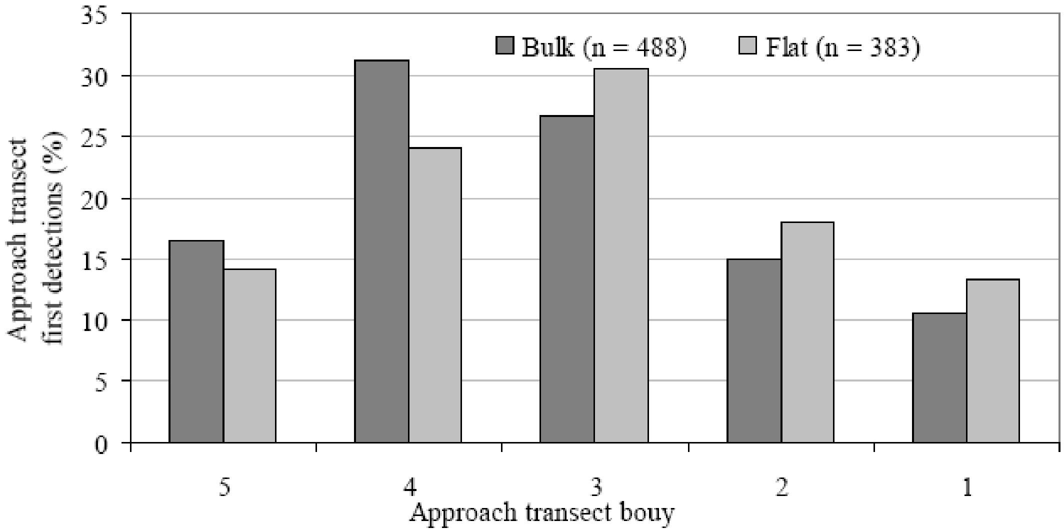

Figure 4.2. Approach Patterns for Radio-Tagged Subyearling Chinook Salmon During Bulk and Flat Spill Treatments at Ice Harbor Dam in 2004. Source: Ogden et al. 2005, Figure 6.

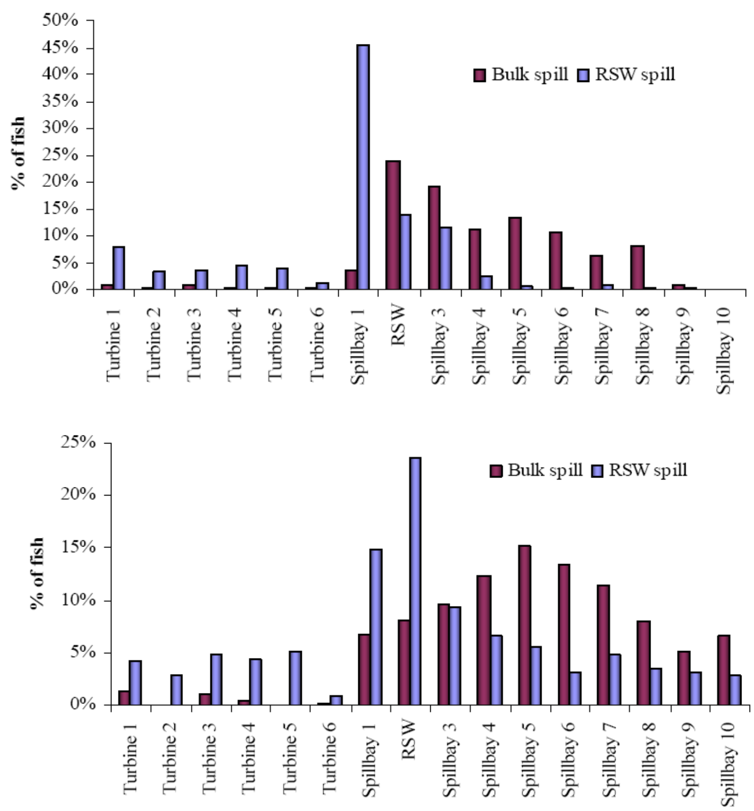

Figure 4.3. First Approach Location of Yearling Chinook Salmon (top) and Juvenile Steelhead (bottom) at Ice Harbor Dam During Two Spill Treatments in 2005. Source: Axel et al. 2007a, Figure 5 and 6.

4.2 Forebay Residence Times

Residence time in the forebay was measured from detection at a point upstream to the instant of passage. Increases in residence time are also referred to as increases in forebay delay. The results of studies conducted between 2001 and 2005 on juvenile steelhead and yearling and subyearling Chinook suggest that residence time in the forebay is influenced by spill. Forebay residence times were consistently shorter during treatments with higher spill proportions (i.e., BiOp versus 50% spill) and with larger spillgate openings and higher spill proportions (bulk versus flat spill) (Table 5.1). RSW operations with lower spill proportions resulted in higher forebay residence times than for bulk spill at BiOp levels. However, only one study out of seven found a statistically significant difference ($P<0.05$) in residence time between spill treatments. The median forebay residence time for yearling Chinook salmon in 2001, a low flow year with zero spill, was more than twice as long as during the other years evaluated.

Table 4.1. Median Forebay Residence Times (hours) at Ice Harbor Dam

Year	Spill Treatment	Yearling Chinook	Steelhead	Subyearling Chinook	Source
2001	BiOp Spill[(a)]	7.3[(a)]	–	–	Axel et al. 2003
2003	BiOp Spill	1.1	–	–	Eppard et al. 2005c
	50% Spill	1.8	–	–	
2004	Bulk Spill	1.4	1.8	3	Eppard et al. 2005a
	Flat Spill	2.4	3.1	4.3	
2005	Bulk Spill	1.4	1.5	4	Ogden et al. 2007
	RSW Spill	2.3	1.9	5	
2006	BiOp Spill	1.1	1.1	2.0	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill	1.8	1.9	–	

(a) No spill except for May 19 (BiOp spill pattern).
– = Insufficient fish detected or data not provided.

4.3 Vertical Distributions

Vertical distributions of fish can have an important influence on their route of passage because of the vertical extent of typical passage routes (Figure 4.4). Fish must move vertically to enter a passage route that does not include the depth at which they are approaching the dam. The available information about vertical fish distributions was collected during hydroacoustic evaluations of fish passage in 2003, 2005, and 2006 (Ham et al. 2007; Moursund et al. 2004; Moursund et al. 2007). Those studies monitored fish just upstream of each type of passage route, and therefore reflect the distributions of fish just prior to passage. Hydroacoustics detects all fish within the target size range, so results include a combination of species dominated by yearling Chinook salmon and steelhead in the spring and a combination overwhelmingly dominated by subyearling Chinook salmon in the summer.

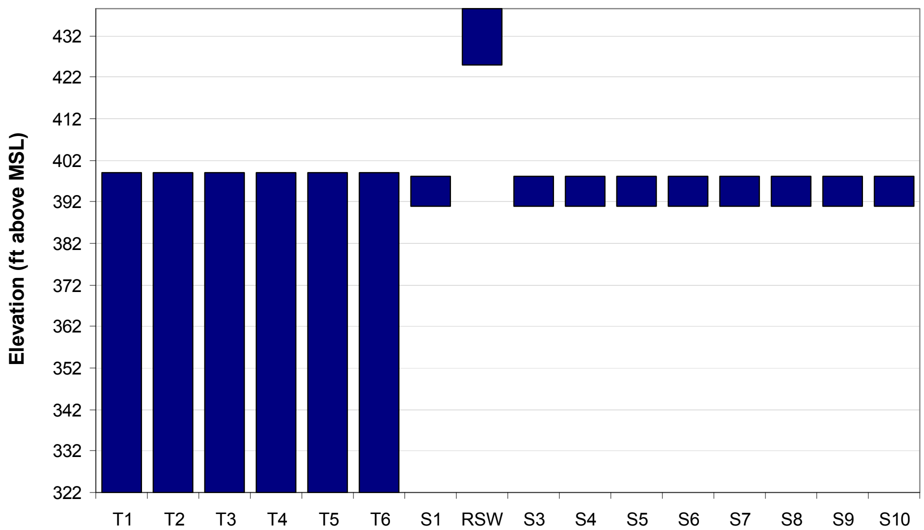

Figure 4.4. Depths of Passage Routes at Ice Harbor Dam

Obvious seasonal differences in vertical distribution across a variety of studies and conditions suggest either that the fish populations included in each season differed in their vertical distribution or that seasonal conditions influenced the vertical distribution. These seasonal differences were large relative to typical differences among spill treatments. Seasonal differences in vertical distribution were also reflected in seasonal differences in fish guidance efficiency. The large seasonal variation in vertical distribution is something that fish managers should consider when planning fish passage, but the evidence does not suggest that these variations can be overcome by the application of specific operations or configurations.

At the spillway, vertical distributions just upstream of the spillgate differed with the size of the spillgate opening (Figure 4.5). At small gate openings, there was only a slight seasonal difference in the vertical distribution (Moursund et al. 2004). The seasonal difference increased as gate opening increased, and was large at a 7-foot gate opening. At the 7-foot opening, fish passed notably higher in the water column in spring than in summer. At small gate openings, fish must pass through an opening only a few feet high, which causes their vertical distribution to be compressed and deep in the water column. At larger gate openings, fish are distributed through more of the water column at the sample location and are drawn from higher in the water column.

Vertical distributions at the powerhouse show fish distributed near the turbine intake ceiling, with unguided fish passing near the screen tip (Figure 4.6). Seasonal differences were less obvious at these locations within the turbine intake than at the spillway.

Seasonal differences in vertical distribution overshadowed the small differences between a gas cap treatment (with 45 kcfs spill during the day with spill to the gas cap at night) and the RSW treatment (with 30% spill 24 hours a day) in 2005 (Moursund et al. 2007). The seasonal trend of summer fish traveling deeper in the water column was more pronounced for fish passing over the RSW than for fish passing through the spillway (Figure 4.7). The vertical distribution for both guided and unguided fish through the turbine intake shows that fish were distributed at shallower depths during the spring and summer seasons under the RSW spill treatment (Figure 4.8).

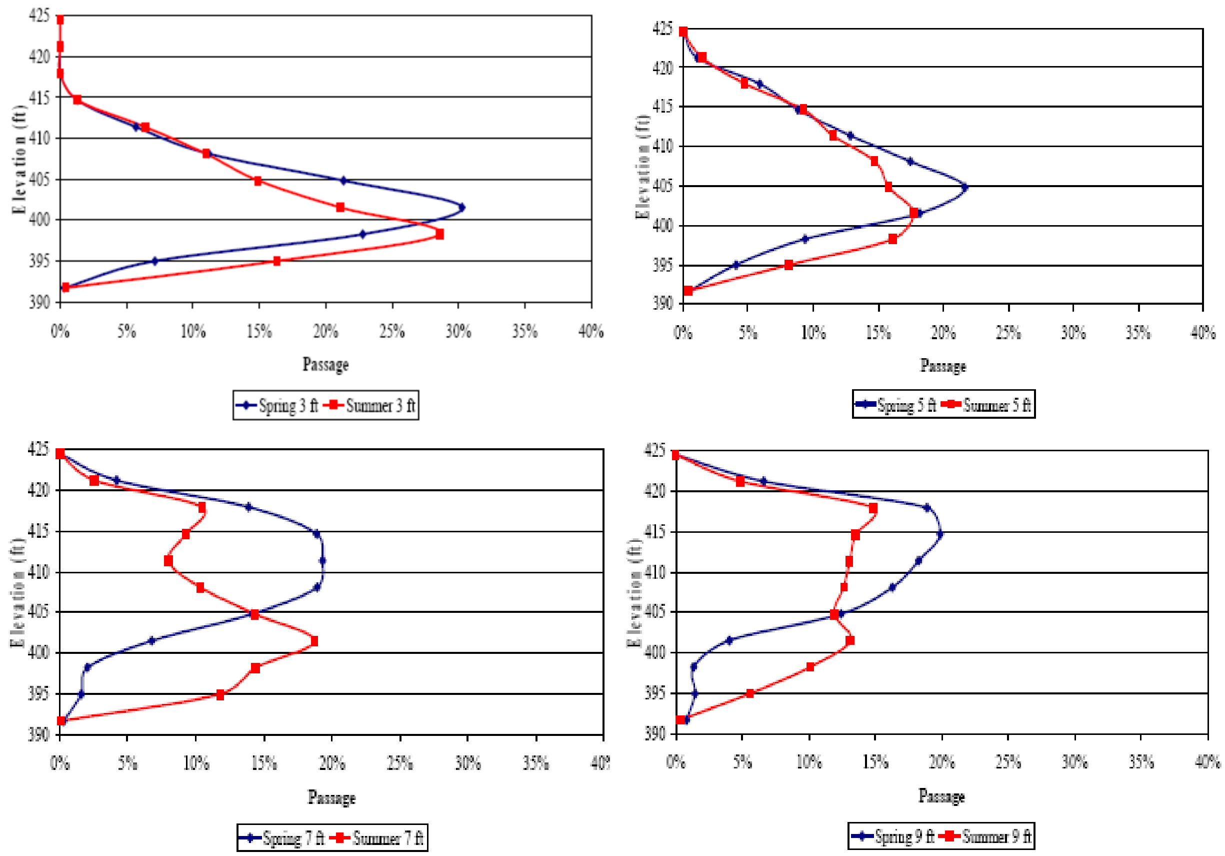

Figure 4.5. Vertical Distribution of Fish Abundance at Various Gate Openings at Ice Harbor Dam in 2003. Source: Moursund et al. 2004, Figures 3.42–3.46.

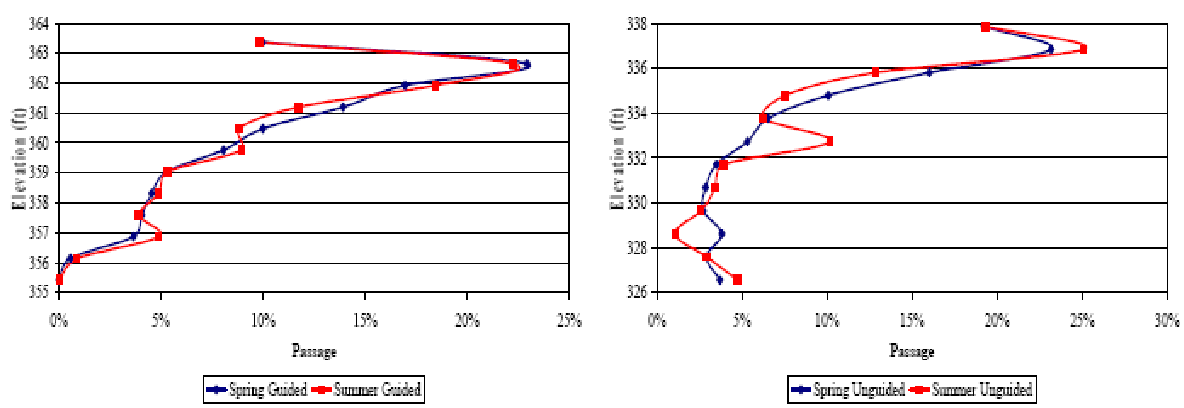

Figure 4.6. Vertical Distribution of Fish Abundance at Guided and Unguided Powerhouse Deployments at Ice Harbor Dam in 2003. Source: Moursund et al. 2004, Figure 3.41.

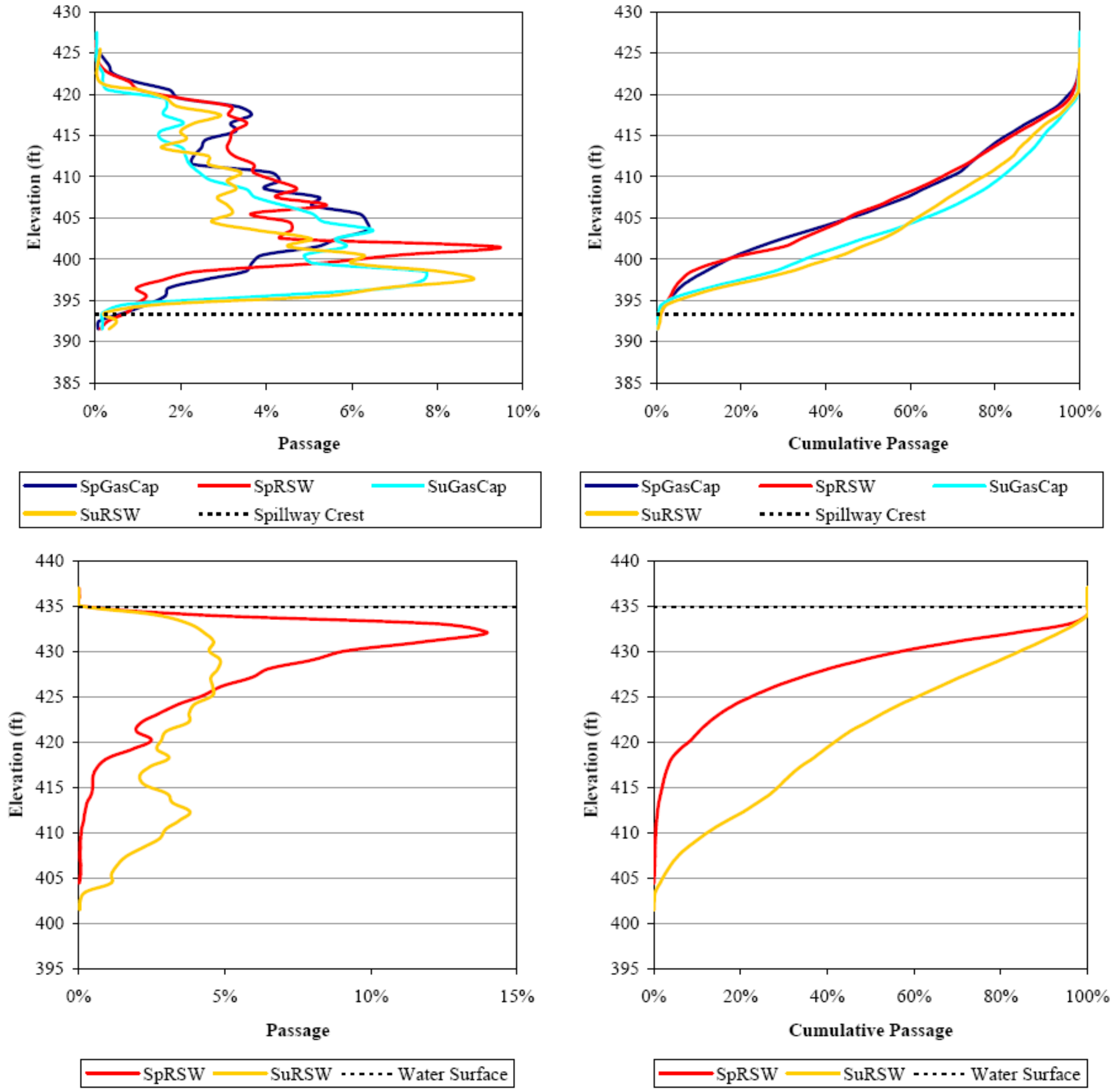

Figure 4.7. Vertical Distributions by Season and Treatment for Fish Passing Through Spillbays (top) and the RSW (bottom) at Ice Harbor Dam in 2005, Shown as Both Relative (left) and Cumulative (right) Fish Abundance by Elevation. Source: Moursund et al. 2007, Figures 3.53 and 3.54.

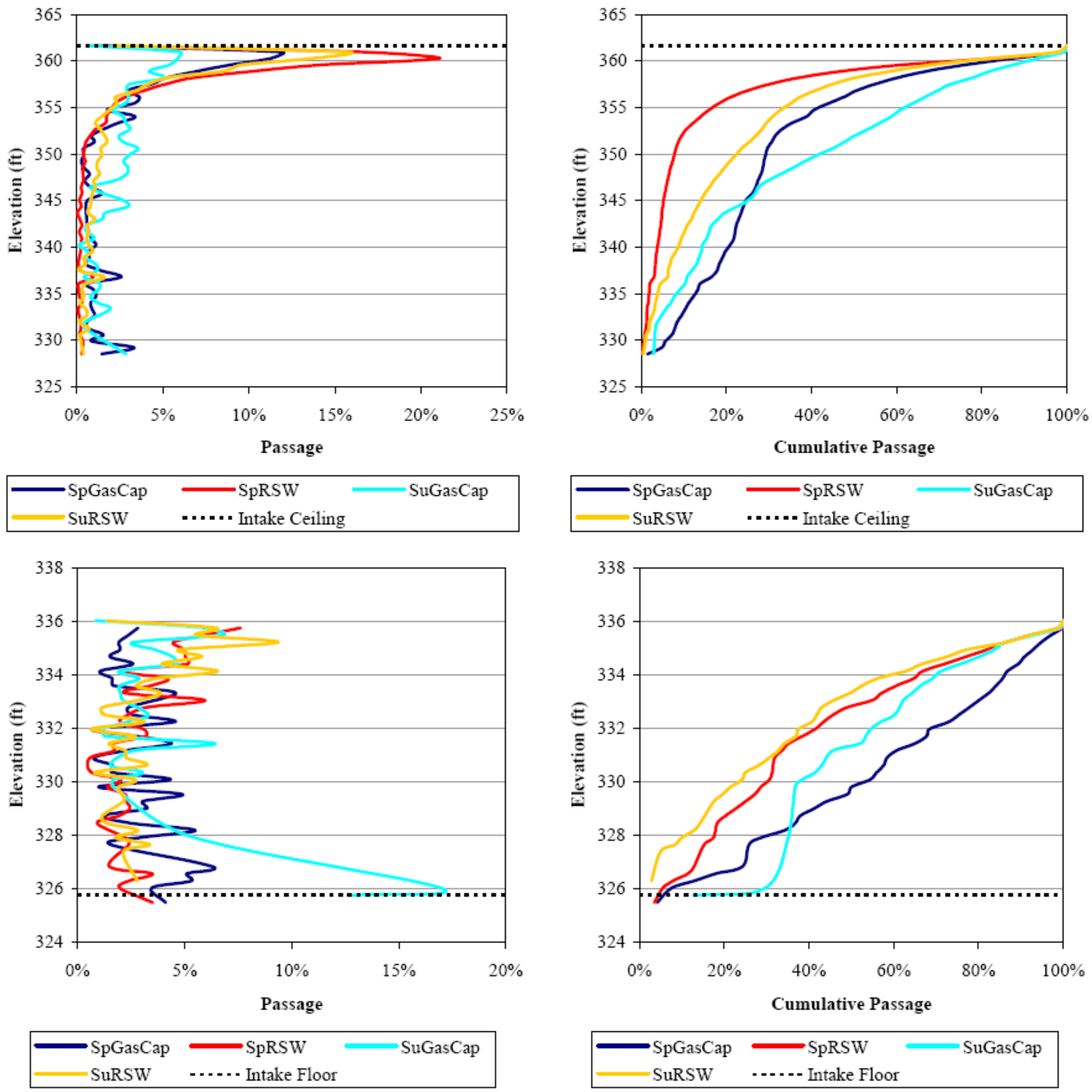

Figure 4.8. Vertical Distributions by Season and Treatment for Guided Fish (top) and Unguided Fish (bottom) Shown as Both Relative (left) and Cumulative (right) Fish Abundance by Elevation at Ice Harbor Dam in 2005. Source: Moursund et al. 2007, Figures 3.51 and 3.52.

In 2006, seasonal differences in vertical distributions of fish passing through the RSW were obvious: Fish entering the RSW during the summer were distributed at greater depths than in the spring. The RSW was operated in all treatments, so it was possible to compare vertical distributions among treatments. Vertical distributions differed only slightly between a 30% spill treatment and a gas cap treatment, in spite of relatively large differences in spill proportion between treatments (Figure 4.9).

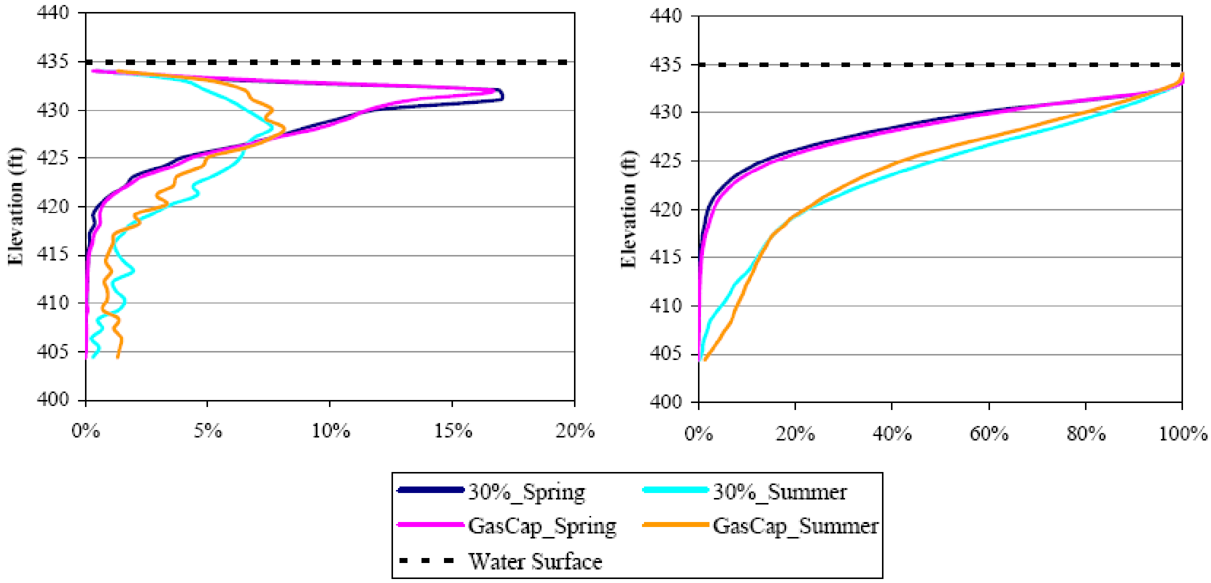

Figure 4.9. Relative (left) and Cumulative (right) Vertical Distributions by Spill Treatment at the RSW at Ice Harbor Dam in 2006. Source: Ham et al. 2007, Figure 3.21.

4.4 Synthesis and Conclusions for Fish Distribution and Movement in the Forebay

The proportion of spill appeared to influence forebay residence times, forebay distributions, and approach distributions of fish. Increasing spill resulted in a higher proportion of fish approaching the spillway. Forebay residence times decreased with increasing spill. The influence of larger spillgate openings and RSW operation on forebay residence times and distributions, if any, was obscured by treatment tests that also varied spill proportion among treatments. Spillgate opening size had a strong influence on the vertical distributions of fish approaching a spillbay, but the tested variety of dam operations had limited influence on fish vertical distributions just upstream of other passage routes.

5.0 Juvenile Salmonid Passage

Studies of fish passage typically focus on a comparison of experimental treatments, which can include varying the operation or configuration of the dam to influence fish passage. Passage distributions and passage metrics are compared among treatments to determine which treatment more nearly meets passage goals. In the following sections, we synthesize these studies to identify common trends and relationships that can inform decisions that seek to optimize fish passage.

Fish passage has been evaluated using radio-telemetry (Axel et al. 2003; Axel et al. 2007a; Eppard et al. 2002; Eppard et al. 2005a; Eppard et al. 2005b; Eppard et al. 2005c; Ogden et al. 2005; Ogden et al. 2007) and hydroacoustic (Ham et al. 2007; Moursund et al. 2004; Moursund et al. 2007) techniques. The studies contrasted spill levels (BiOp versus 50% spill), spill patterns (bulk versus flat), and configurations (RSW versus bulk spill).

5.1 Fish Passage Route Distributions

Project-wide studies of fish passage using radio telemetry or hydroacoustics typically monitor passage through each available route at the dam. This comprehensive coverage allows passage distributions to be summarized in various ways, depending upon the objectives of the study. Passage proportions can be reported for each major passage route type to illustrate whether a specific treatment is having the expected effect on routing. Passage proportions can be reported for each passage location to allow a more detailed examination of passage routing. Because many studies are designed to contrast experimental treatments that differ in the distribution of water discharge among routes, it is often useful to display the distribution of discharge alongside passage results to more easily interpret passage route distributions.

Table 5.1 illustrates the distribution of fish passage by major route type for a series of studies across a variety of conditions. These results suggest that bulk spill conditions decreased turbine passage for spring migrants relative to flat spill conditions. RSW operation resulted in fewer steelhead and yearling or subyearling Chinook salmon passing over the spillway (including the RSW) than for a bulk pattern at BiOp spill levels. It is important to remember that the RSW treatment included approximately half as much spill as the bulk treatment, so the difference is a combination of RSW operation and a lower spill proportion. Turbine passage was notably higher during the RSW treatment for yearling and subyearling Chinook salmon, although the total proportion passing through the turbines remained less than 7%.

Table 5.1. Distribution of Passage Among Routes at Ice Harbor Dam

Species	Year	Spill Treatment	Spillway Passage (%)	JBS Passage (%)	Turbine Passage (%)	RSW Passage (%)	Unknown Passage Route (%)	No Passage (%)	Passage Not Detected (%)	Source
Yearling Chinook Salmon	2001	Zero Spill[(a)]	0.0	63.8	4.6[(a)]	–	25.9	4.3	1.4	Axel et al. 2003
	2003	BiOp Spill	93.1	4.1	2.8	–	0.0	0.0	0.0	Eppard et al. 2005c
		50% Spill	82.1	8.8	9.2	–	0.0	0.0	0.0	
	2004	Bulk Spill	92.2	1.3	0.2	–	1.2	0.0	5.1	Eppard et al. 2005a
		Flat Spill	81.4	6.9	1.8	–	2.7	0.0	7.1	
	2005	RSW Spill	47.9	15.5	6.6	28.9	1.1	0.0	0.0	Axel et al. 2007a
		Bulk Spill	97.4	1.1	0.4	–	0.0	0.0	0.0	
	2006	BiOp Spill	46.2	15.1	4.9	33.1	0.7	0.0	0.0	Axel et al. 2007b
		30–40% Spill	22.1	19.1	7.5	51.3	0.0	0.0	0.0	
Steelhead	2004	Bulk Spill	99.0	1.0	0.0	–	0.0	0.0	0.0	Axel et al. 2005
		Flat Spill	82.0	17.0	1.0	–	0.0	0.0	0.0	
	2005	RSW Spill	29.0	20.0	2.0	47.0	1.0	0.0	0.0	Absolon et al. 2007
		Bulk Spill	96.0	2.0	1.0	–	1.0	0.0	0.0	
	2006	BiOp Spill	49.8	17.9	1.4	30.9	0.0	0.0	0.0	Axel et al. 2007b
		30–40% Spill	23.8	36.7	2.0	37.5	0.0	0.0	0.0	
Subyearling Chinook Salmon	1997	Not Reported	82.0	6.6	7.4	–	–	–	–	Eppard et al. 1998
	2004	Bulk Spill	78.1	1.3	0.9	–	3.6	0.0	16.2	Ogden et al. 2005
		Flat Spill	84.1	3.0	0.9	–	1.7	0.0	10.2	
	2005	RSW Spill	27.0	8.0	5.0	60.0	0.0	0.0	0.0	Ogden et al. 2007
		Bulk Spill	98.0	1.0	1.0	–	0.0	0.0	0.0	
	2006	BiOp Spill	24.0	4.3	1.8	68.0	0.2	–	–	Ogden et al. 2008

(a) No spill except for May 19 (BiOp spill pattern).
– = No data or route not operational.

Experimental treatments are set up in 24-hour periods that are often grouped into blocks. At Ice Harbor Dam, the operational daytime period begins at 05:00 and continues to 17:59. Nighttime begins at 18:00 and extends to 4:59 the following morning. The operations during these diel periods can vary widely, and it is important to consider the entire 24-hour period to understand the influence of a treatment on fish passage. Figure 5.1 illustrates operations and hydroacoustic estimates of passage during diel periods for each treatment. The daytime operations of the BiOp treatment (upper panel) were very similar to the operations of the 50% spill treatment (lower panel) during day and night and daytime passage was somewhat similar among treatments. BiOp operations during the night resulted in a higher proportion of spill and therefore greater spill passage during the night. Because fish passage proportions tend to exceed the flow proportion for spillway routes, this graphic reveals a tendency of fish to pass over the spillway in greater proportion than the proportion of flow passing over the spillway. A comparison of bulk and zero spill treatments during the summer revealed a striking contrast between the distribution of flow between the powerhouse and spillway and a similar contrast in passage distributions among treatments (Figure 5.2).

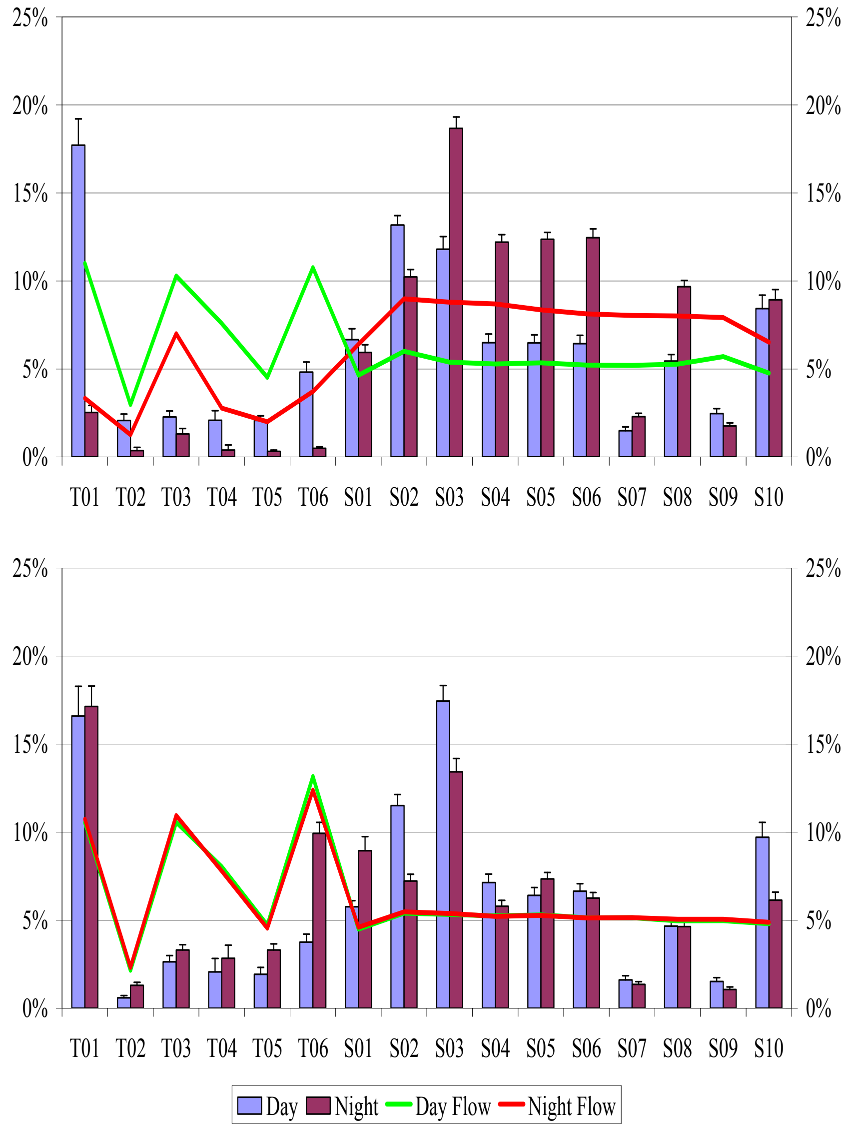

Figure 5.1. Passage and Flow Distributions During BiOp (top) and 50% Spill (bottom) Treatments at Ice Harbor Dam During the Spring of 2003. Error Bars are 95% confidence intervals. Source: Moursund et al. 2004, Figure 3.28.

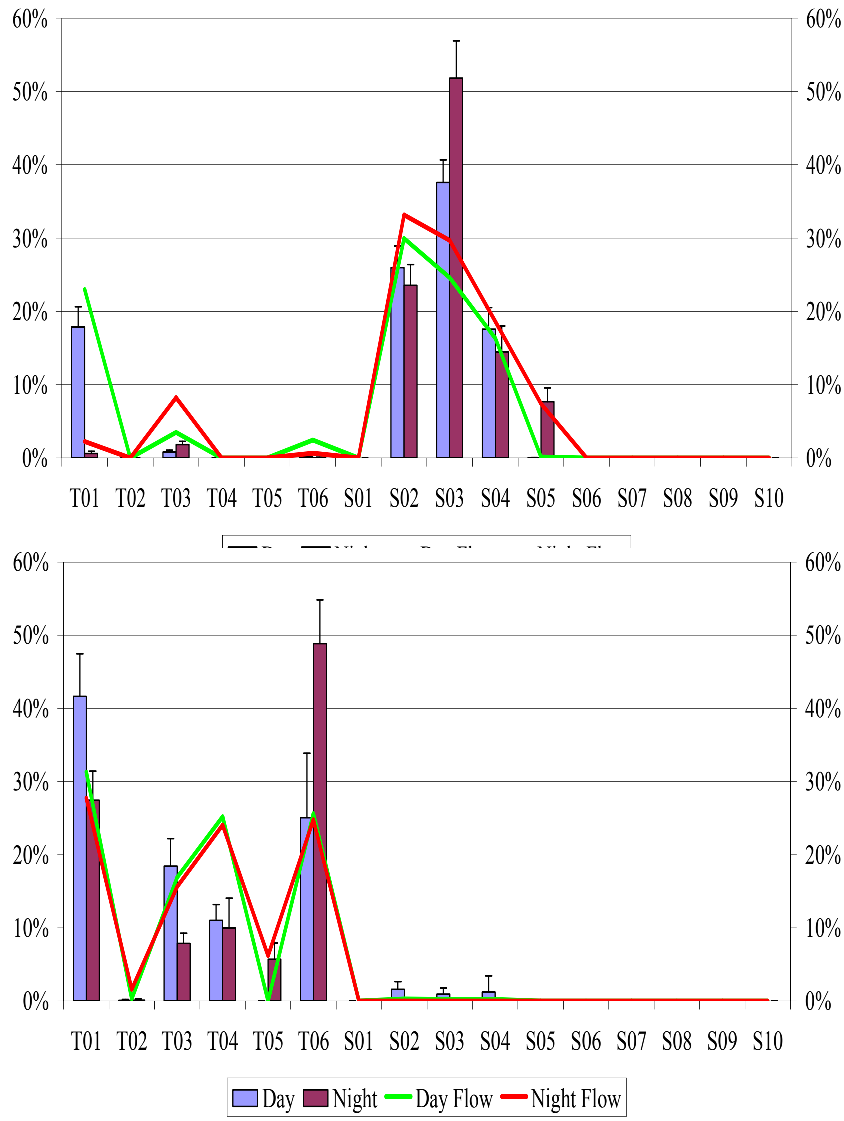

Figure 5.2. Passage and Flow Distributions During Bulk BiOp Spill (top) and Zero Spill (bottom) Treatments at Ice Harbor Dam During the Summer of 2003. Error Bars are 95% confidence intervals. Source: Moursund et al. 2004, Figure 3.33.

Another approach to examining the influence of flow distribution among routes is to consider the proportion of time that a route is available for passage. This gives somewhat different results than the proportion of flow approach used above because spill gates can be opened to achieve a wide range of discharges within each spillbay. Figure 5.3 illustrates how operations and passage of yearling Chinook salmon differed between bulk and flat spill treatments. The bulk spill pattern concentrated discharge and fish passage nearer the middle of the spillway. The passage distribution of subyearling Chinook salmon at the spillway appears to be closely linked to the treatment pattern of spill (Figure 5.4).

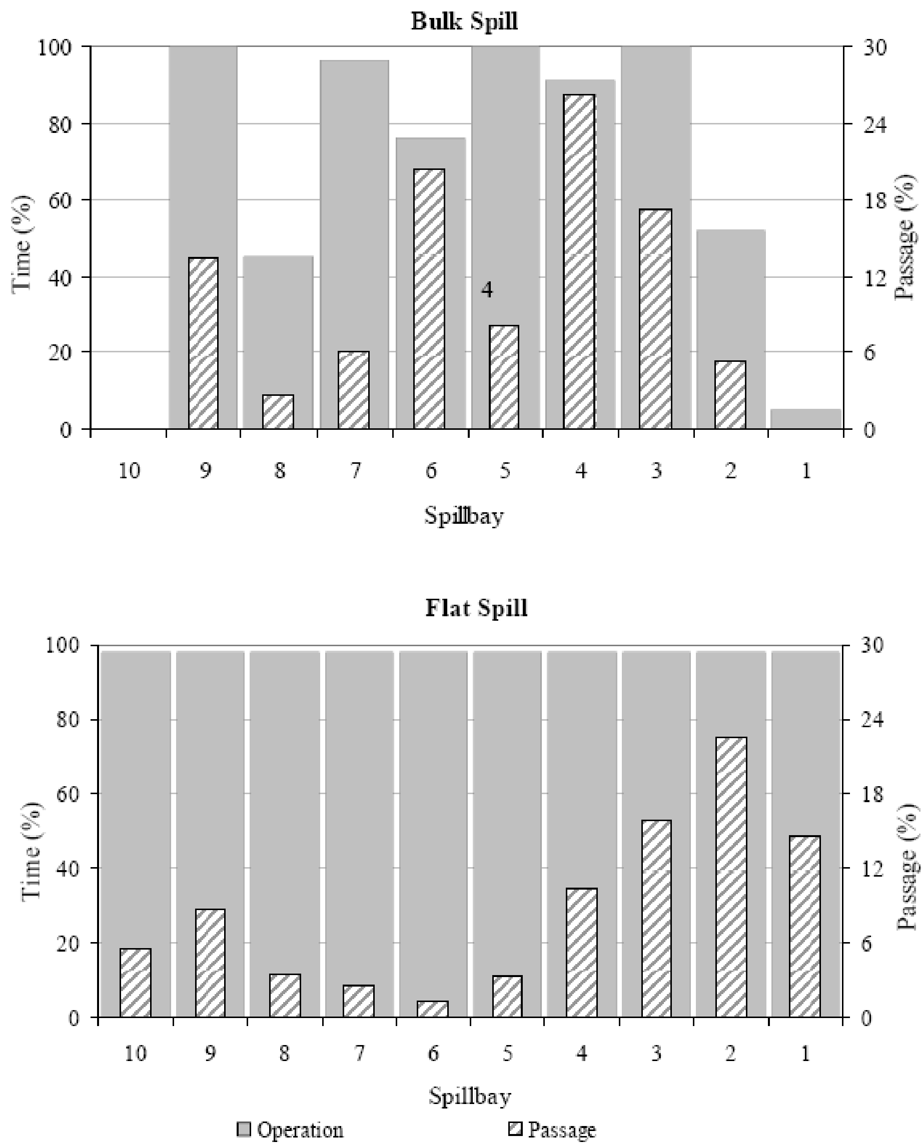

Figure 5.3. Passage Distribution of Radio-Tagged Yearling Chinook Salmon During Bulk and Flat Spill Treatments at Ice Harbor Dam in 2004. Source: Eppard et al. 2005a, Figure 9.

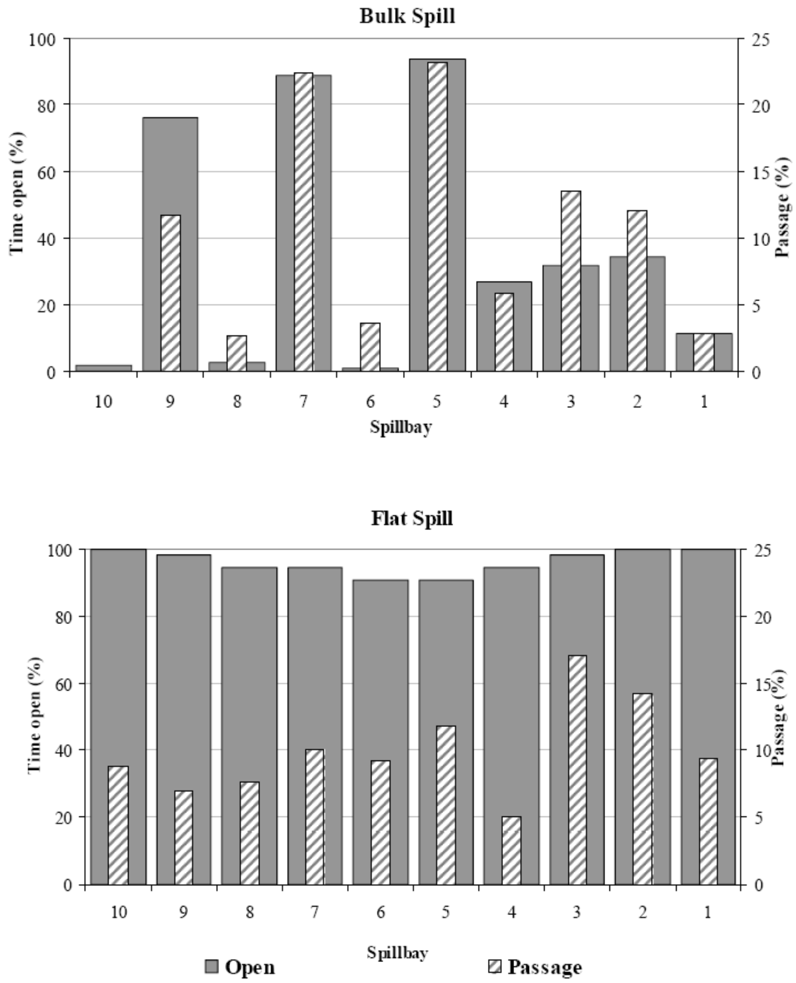

Figure 5.4. Passage Distribution of Radio-Tagged Subyearling Chinook Salmon During Bulk and Flat Spill Treatments in 2004. Source: Ogden et al. 2005, Figure 9.

During 2005, passage during the RSW treatment differed notably from that during the bulk spill treatment for all three species studied with radio telemetry (Figure 5.5, Figure 5.6, and Figure 5.7). Because the treatments differed in the operation of the RSW, the amount of spill, and the pattern of spill, it is difficult to determine which of these factors was most influential. The passage distributions from the hydroacoustic study of the same year included flow distributions (Figure 5.8 and Figure 5.9). These figures indicate that the proportion of fish passing over the RSW far exceeded the proportion of flow passing over the RSW. This divergence is an indication of the effectiveness of this structure for fish passage and is an indication that performance differences among treatments are being influenced by the operation of the RSW, not just differences in the amount or pattern of spill.

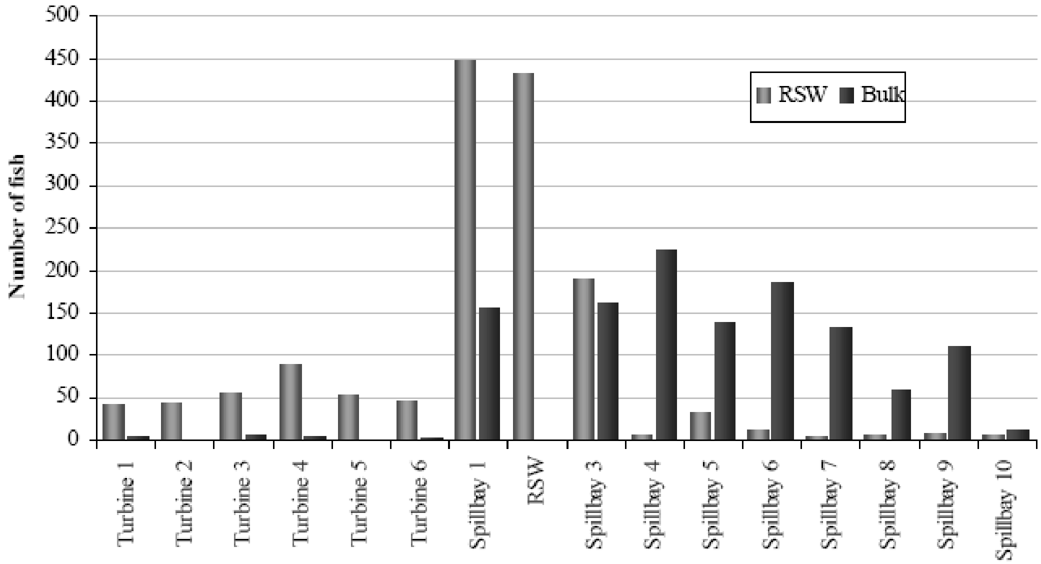

Figure 5.5. Horizontal Passage Distribution for Radio-Tagged Yearling Chinook Salmon at Ice Harbor Dam During Bulk Spill and RSW Spill Treatments in 2005. Source: Axel et al. 2007a, Figure 17.

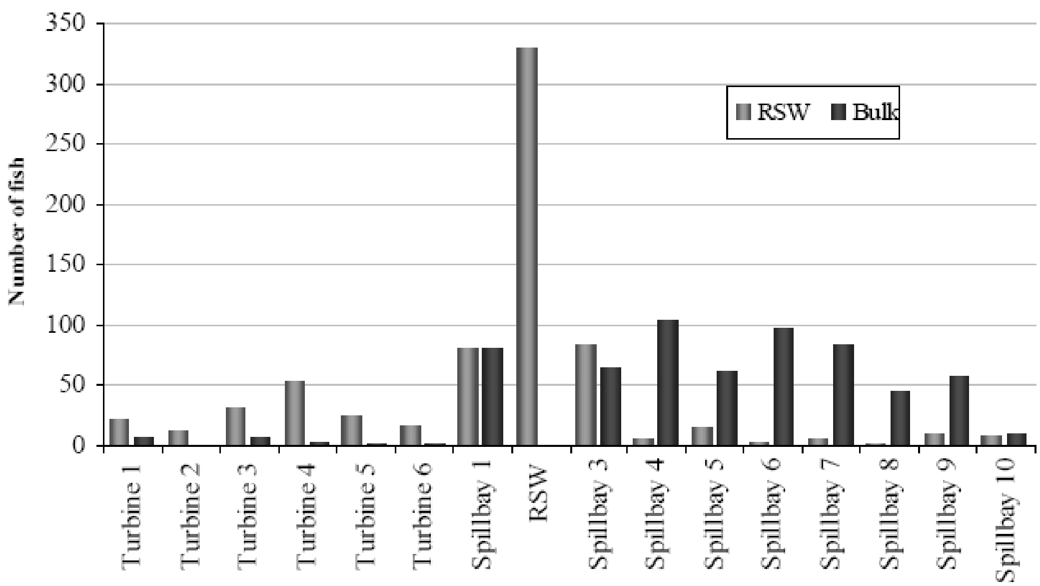

Figure 5.6. Horizontal Passage Distribution for Radio-Tagged Steelhead at Ice Harbor Dam During Bulk Spill and RSW Spill Treatments in 2005. Source: Axel et al. 2007a, Figure 20.

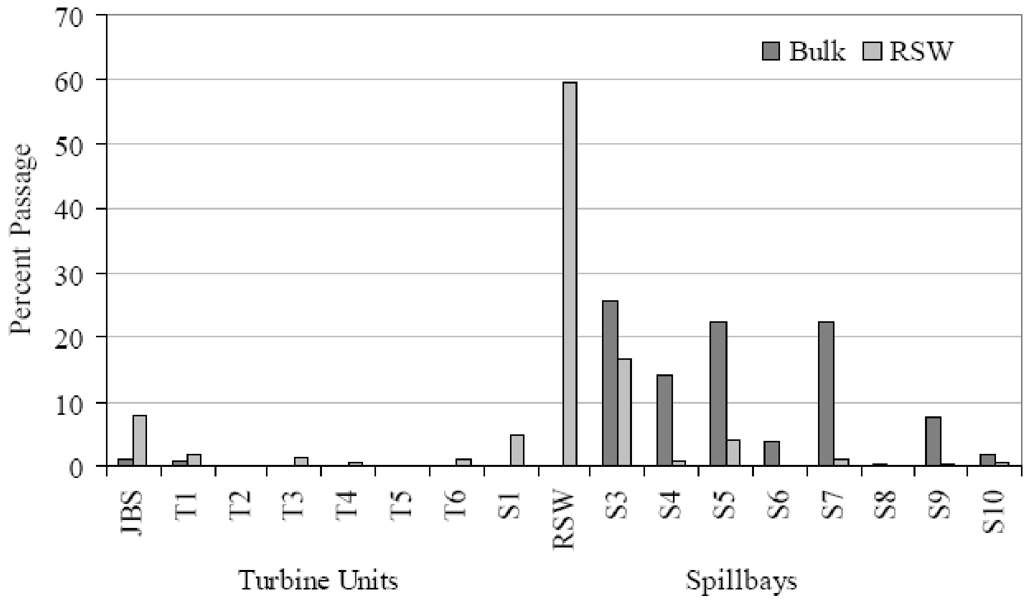

Figure 5.7. Horizontal Passage Distribution for Radio-Tagged Subyearling Chinook Salmon at Ice Harbor Dam During Bulk Spill and RSW Spill Treatments in 2005. Source: Ogden et al. 2007, Figure 8.

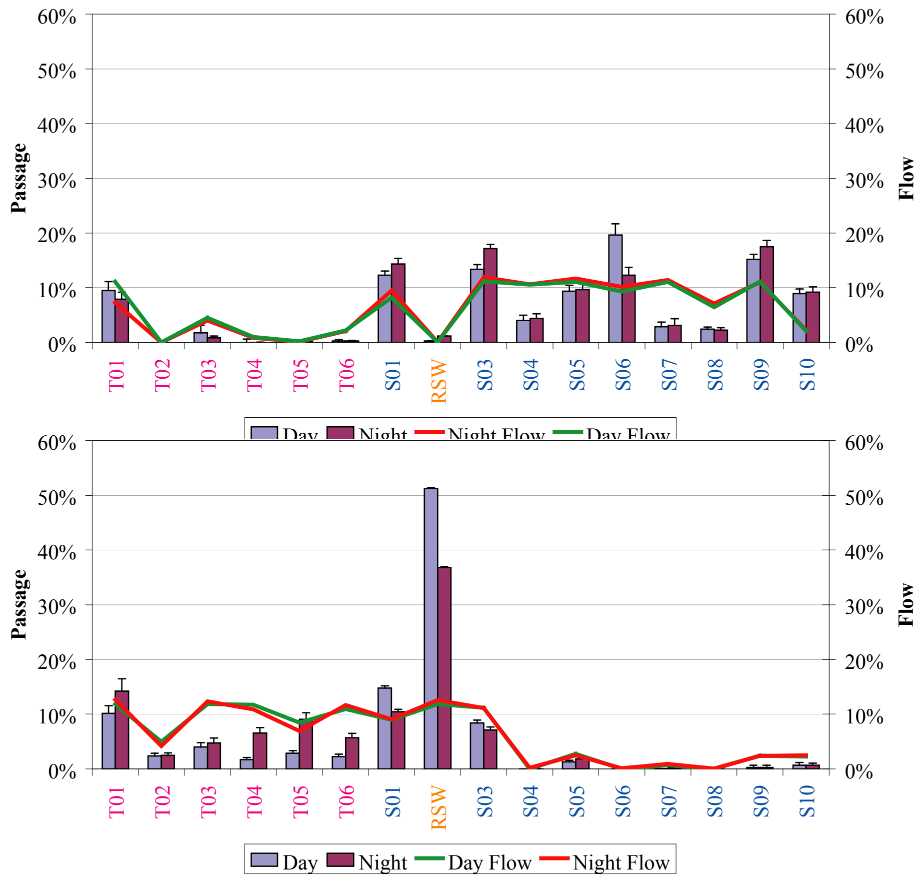

Figure 5.8. Horizontal Distribution of Passage and Flow During Gas Cap Spill (top) and RSW Spill (bottom) at Ice Harbor Dam During the Spring in 2005. Error Bars are 95% confidence intervals. Source: Moursund et al. 2007, Figure 3.47 and Figure 3.48.

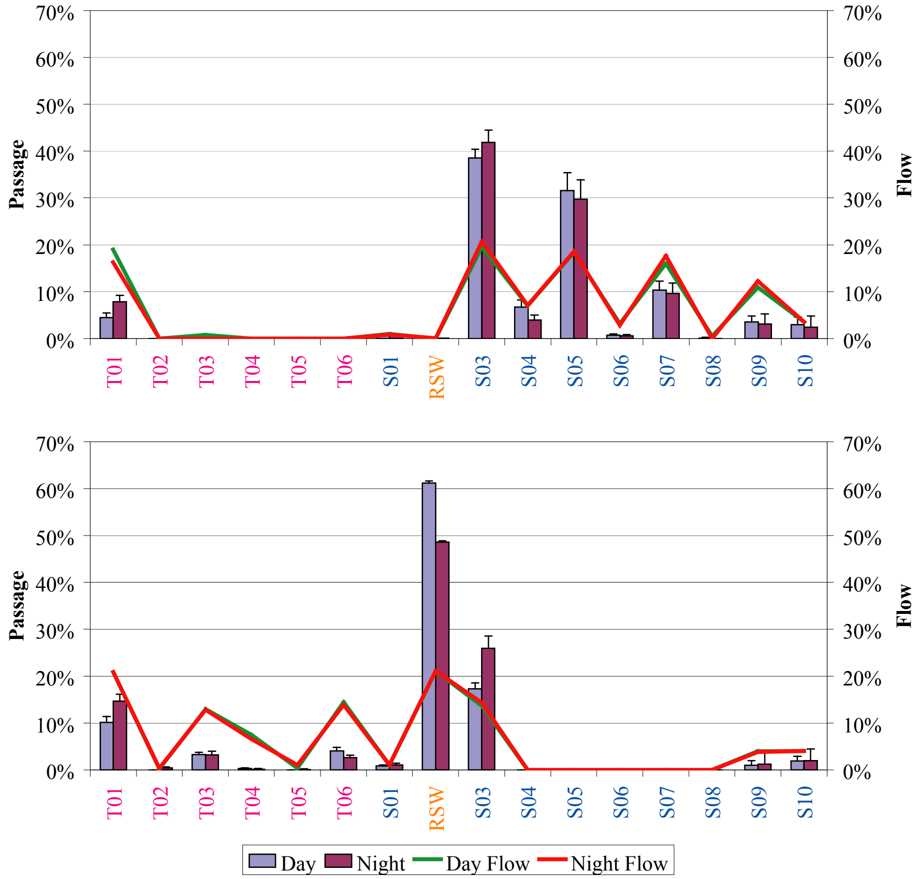

Figure 5.9. Horizontal Distribution of Passage and Flow during Gas Cap Spill (top) and RSW Spill (bottom) at Ice Harbor Dam During the Summer in 2005. Error Bars are 95% confidence intervals. Source: Moursund et al. 2007, Figure 3.49 and Figure 3.50.

5.2 Project-Wide Passage Metrics

The route-specific passage estimates computed using radio-telemetry or hydroacoustic methods are often summarized by computing fish passage performance measures. These project-wide passage metrics emphasize various aspects of fish passage of importance to fisheries managers. Fish passage efficiency (FPE) is the proportion of fish that pass through non-turbines routes at the dam and spill passage efficiency (SPE) is the proportion of fish that pass via the spillway. Spill passage effectiveness (SPS) is the ratio of the proportion of fish passing over the spillway versus the proportion of water passing over the spillway; it is intended to describe the relative effectiveness that a particular passage route has at passing fish per unit of water. Fish guidance efficiency (FGE) is the proportion of fish guided into the JBS by the intake screens. Two additional metrics are now applicable with the installation of the RSW at Ice Harbor Dam. RSW passage efficiency (RPE) is the proportion of fish that pass via the RSW. The term RPE is obsolete, and the new standard term is surface outlet passage efficiency (SOE). RSW passage effectiveness (RPS) is the ratio of the proportion of fish passing through the RSW versus the proportion of water passing over the RSW. The term RPS is obsolete, and the new standard term is surface outlet passage effectiveness (SOS).

The following sections evaluate these project-wide fish passage performance measures and seek to identify relationships with covariates based upon the operation or configuration of the dam as well as other environmental factors.

5.2.1 Effect of Spill Flow on Spillway Passage Efficiency

It is reasonable to expect SPE to increase with increasing spill, but by how much? When there is zero spill, SPE must be zero. As spill approaches 100%, SPE approaches 100%. Between those extremes, the proportion of fish passing the spillway at a given proportion of water spilled is dependent upon the propensities of the fish and the configuration and operation of the dam. Are juvenile steelhead more or less likely to encounter a spillway route than a turbine route? Do spillway routes have characteristics that are attractive to yearling Chinook salmon seeking a downstream passage route? Such phenomena or behaviors are not well understood, but the empirical evidence provided by the results of passage studies are examined here for evidence of the influence of unspecified factors on where fish pass.

The most notable differences in SPE among spill treatments were those between bulk and RSW spill treatments in 2005 (Table 5.2). Those treatments differed in the operation of the RSW, but the RSW treatment also included a much lower proportion of spill. Lower SPE estimates were found for treatments with reduced spill proportion, which should be expected. In 2005, the treatment with an RSW operating, but with approximately half as much spill resulted in less than a 25% reduction in SPE for all species and monitoring methods.

Table 5.2. Estimates of Spill Passage Efficiency at Ice Harbor Dam

Year	Experimental Treatment	Yearling Chinook Salmon (RT)	Steelhead (RT)	Spring Run at Large (HA)	Subyearling Chinook Salmon (RT)	Summer Run at Large (HA)	Source
2003	BiOp Spill	93.4	–	81.4	–	76.4	Eppard et al. 2005c; Moursund et al. 2004
	50% Spill	82.0	–	56.0	–	65.4	
2004	Bulk Spill	97.7	99.0	–	93.3	–	Eppard et al. 2005a
	Flat Spill	87.5	82.0	–	93.3	–	
2005	Bulk Spill	98.5	96.9	88.7	98.5	92.0	Axel et al. 2007a; Moursund et al. 2007
	RSW Spill	77.6	77.0	61.9	87.3	77.4	
2006	BiOp Spill	87.0	87.9	–	94.0	–	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill	59.3	61.3	–	–	–	

– = Estimates not available due to insufficient fish or no study conducted.
HA = Hydroacoustic
RT = Radio Telemetry

The influence of spill on fish passage can be further evaluated by plotting SPE versus spill proportion. Figure 5.10 plots SPE and spill proportion for the spring passage periods of a number of studies. Several aspects of dam operations are evident in this figure. Data derived from the available studies indicate that Ice Harbor Dam was rarely operated at spill proportions less than 50% in the absence of RSW operation. Operations with the RSW occurred primarily in a narrow band around 30% spill. To emphasize trends in the data across the range of spill proportion, fits were plotted based on LOWESS smoothing (Statistica, Statsoft,Inc.). LOWESS fits were chosen because they are data driven, rather than having a defined form. This allows the fits to reveal trends in the data, if any exist. Where the LOWESS fit becomes irregular, it is likely that the data are too sparse, or too variable, to define a trend across spill proportion. Comparing fits among groups reveals that the LOWESS trend for hydroacoustic estimates of SPE is notably lower than for radio-tagged yearling Chinook salmon or steelhead. Because the run-at-large monitored by hydroacoustic techniques is primarily composed of roughly equal portions of yearling Chinook salmon and steelhead, hydroacoustic estimates would be expected to be similar and intermediate to the two radio-telemetry estimates. The results for all groups suggest that fish passed the spillway in greater proportion than flow.

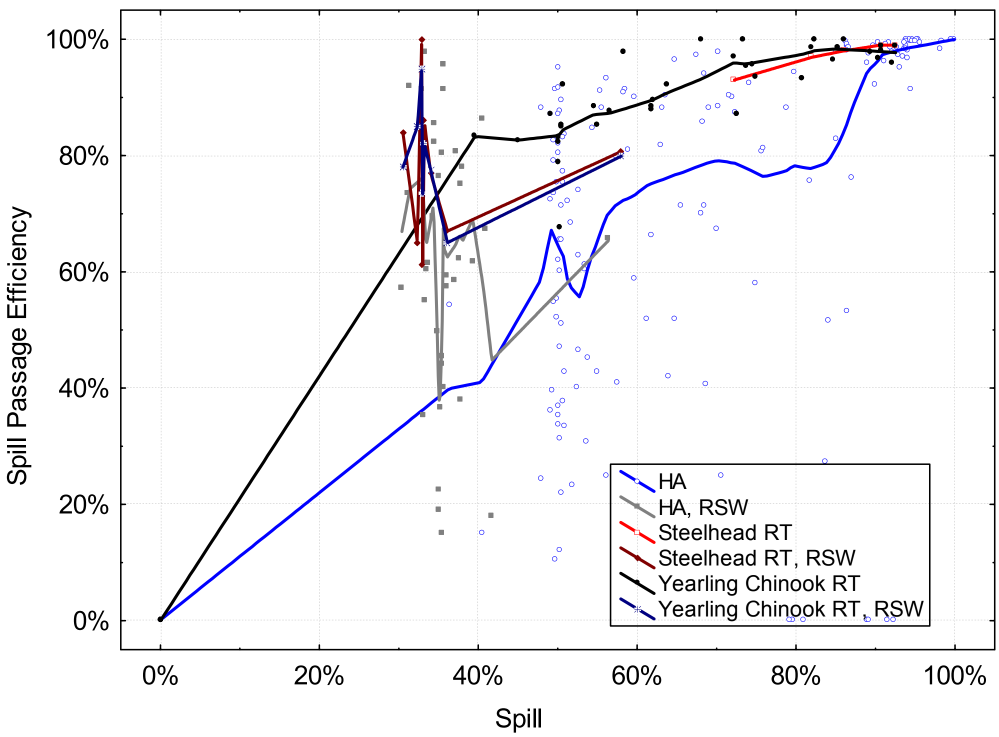

Figure 5.10. Spill Passage Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring. LOWESS fits are used to illustrate trends, if any, in the available data.

The LOWESS fits used above were informative over ranges of spill proportion where data were abundant, but these fits are not informative where data were limited or missing. Spill passage efficiency relationships are typically fit with logit-logit regression that produces curves that asymptote to 0% spill passage at 0% spill and to 100% spill passage at 100% spill. Techniques for fitting logit-logit curves involve simple linear regression techniques, but even these are not immune to poorly distributed data. Given the varying distribution of data among groups, we chose to simplify the fits by holding the slope (in logit-transformed space) to be equal to 1. We have found in other work that well distributed data sets often have a slope near 1. These constraints cause the resulting fitted curves to have a simple shape that is consistent across all groups, but that shape bends to reflect higher or lower SPE for each group at a given spill proportion. This approach is intended to minimize differences that result primarily from the varying distribution of the data among groups, but we do not assume that it will be completely effective in erasing those differences. Figure 5.11 illustrates the resulting curves for groups of spring migrants with the RSW on or off. The trends for hydroacoustic estimates were lower than for any radio-telemetry group. The hydroacoustic estimates also suggest that the SPE decreases during RSW operation, which was not expected. With the RSW off, the trends for yearling Chinook salmon and steelhead were very similar. Spill passage efficiency estimates in radio-telemetry studies appeared to increase with RSW operation for yearling Chinook salmon, with a slight decrease in SPE for steelhead during RSW operation and a slight increase in SPE for yearling Chinook salmon during RSW operation.

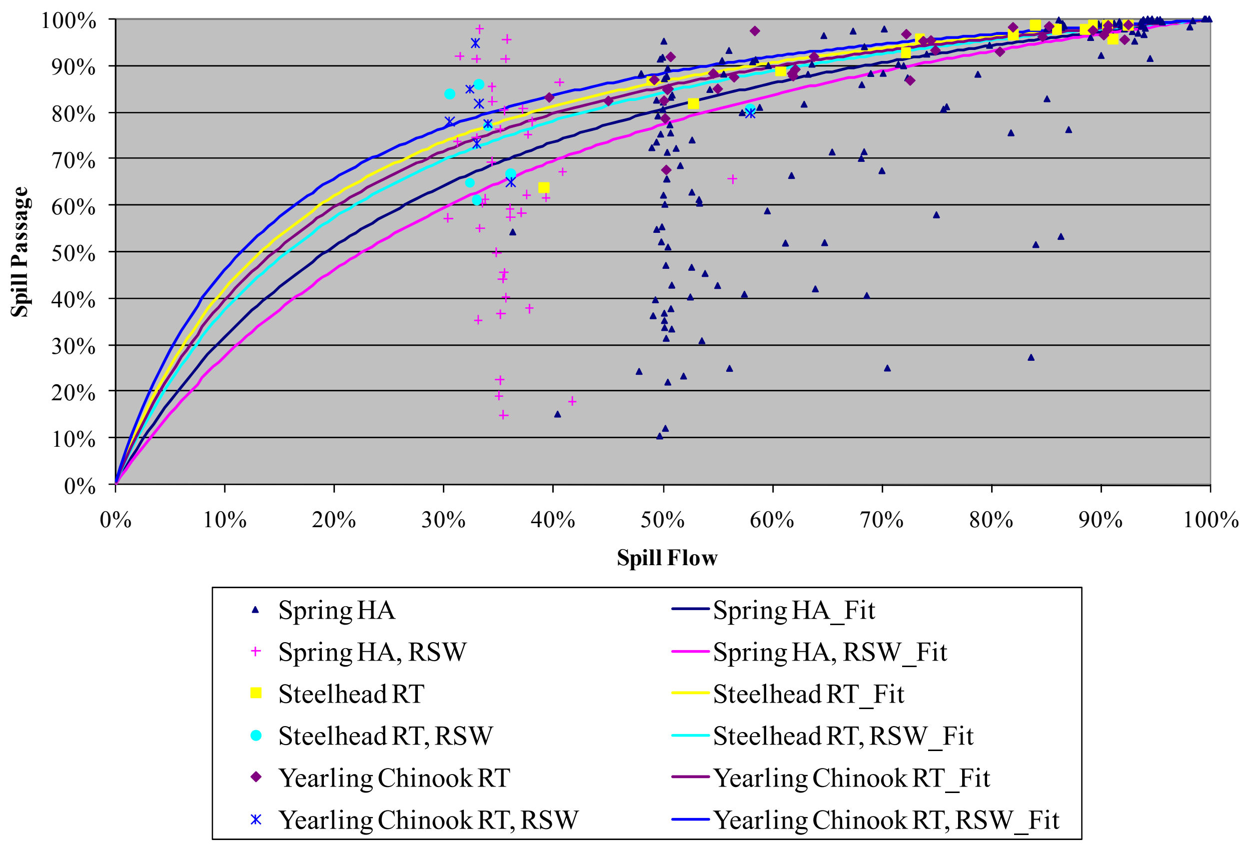

Figure 5.11. Relationships Fit to Spill Passage Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring

The distribution of spill proportions was slightly less clumped during summer, and RSW operations occurred across a broader range of spill proportions (Figure 5.12). During summer periods, Ice Harbor Dam was rarely operated at less than 50% spill in the absence of the RSW, and operations with the RSW fell mostly near 35 to 40%. LOWESS fits of hydroacoustic estimates suggest that SPE increased with the operation of the RSW. Radio-telemetry data suggest that SPE decreased during RSW operation.

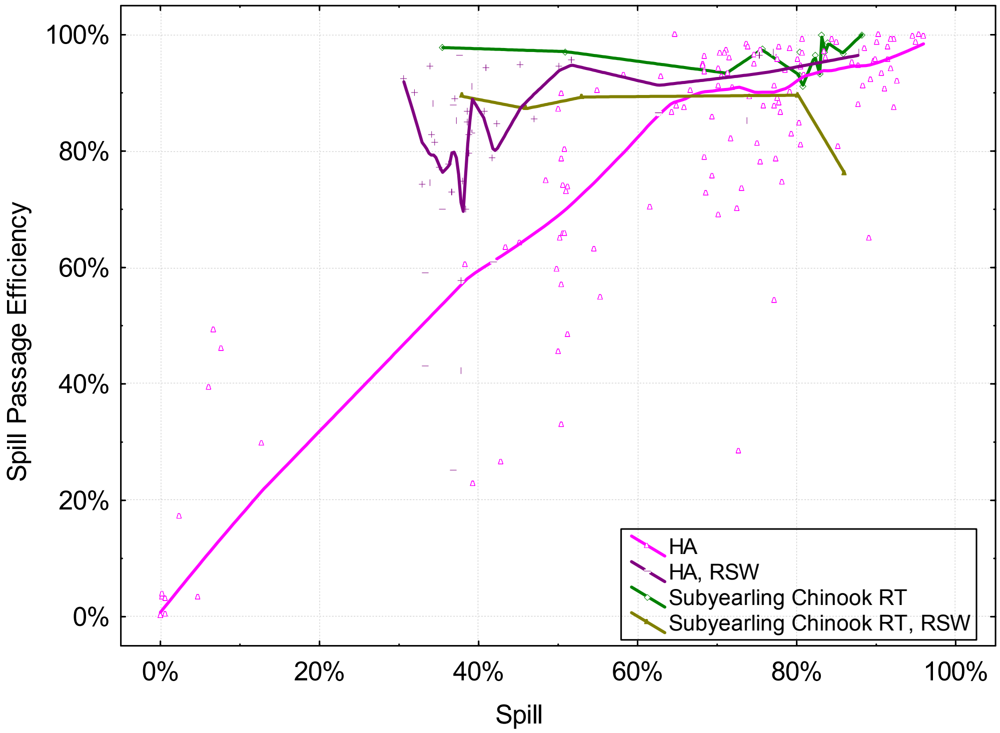

Figure 5.12. Spill Passage Efficiency Plotted Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer. LOWESS fits illustrate trends, if any, in the available data.

Using the same logit-logit curve-fitting approach introduced above, tresnds in SPE were examined among groups for the summer period (Figure 5.11). The curves based on hydroacoustics suggest that RSW operation increased SPE, but the curves based on radio telemetry suggest that RSW operation decreased SPE. The disagreement in the trends suggested by these curves for the two study methods could arise from a bias on the part of one method, but it could also result from the limited quantity and distribution of the data. The conflicting results regarding the contribution of the RSW to SPE indicate that considerable uncertainty about the influence of the RSW remains, given the available studies.

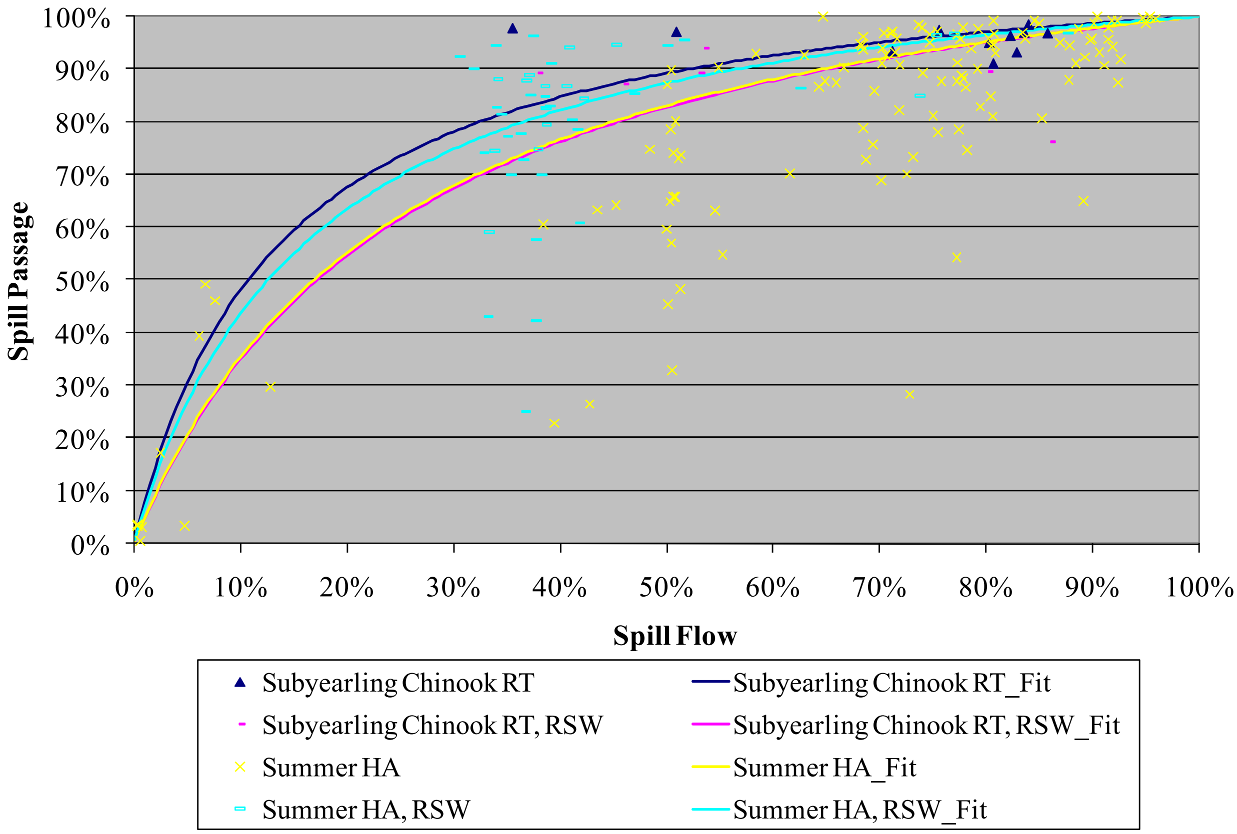

Figure 5.13. Relationships Fit to Spill Passage Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer

5.2.2 Effect of Spill Flow on Spillway Passage Effectiveness

Spill passage effectiveness is high when the proportion of fish passing through the spillway is large relative to the proportion of water passing through the spillway. In examining differences in SPE among treatments across the 3 most recent years of study, the most striking difference arose between bulk spill and RSW spill treatments (Table 5.3). The lower spill proportion combined with RSW operation resulted in a near doubling of spring SPS estimates using radio-telemetry techniques. The trend in hydroacoustic results for spring was similar, but of smaller magnitude. The effectiveness values were very similar across study methods for both treatments during the summer of 2005.

Table 5.3. Estimates of Spill Passage Effectiveness at Ice Harbor Dam

Year	Spill Treatment	Yearling Chinook Salmon (RT)	Steelhead (RT)	Spring Run at Large (HA)	Subyearling Chinook Salmon (RT)	Summer Run at Large (HA)	Source
1997	<40% Spill	–	–	–	2.25	–	Eppard et al. 1998
	40–50% Spill	–	–	–	1.70	–	
	50–60% Spill	–	–	–	1.20	–	
	>60% Spill	–	–	–	1.25	–	
2003	BiOp Spill	1.40	–	1.12	–	1.07	Eppard et al. 2005c; Moursund et al. 2004
	50% Spill	1.60	–	1.01	–	–	
	Bulk Spill	–	–	–	–	1.27	
2004	Bulk Spill	1.20	1.00	–	1.15	–	Eppard et al. 2005a; Ogden et al. 2005
	Flat Spill	1.50	1.08	–	1.19	–	
2005	Bulk Spill	1.19	1.17	1.06	1.17	1.17	Axel et al. 2007a; Moursund et al. 2007
	RSW Spill	2.27	2.24	1.54	1.90	1.98	
2006	BiOp Spill with RSW	1.38	1.39	–	2.00	–	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill With RSW	2.22	1.86	–	–	–	

– = Estimates not available due to insufficient fish or no study conducted.

Plotting SPS versus spill proportion revealed a logarithmic increase in SPS as spill proportion decreased. As spill proportion approaches 100%, SPS approaches 1. The LOWESS fits suggest that hydroacoustic techniques consistently estimated lower SPS during the spring in the absence of RSW operation than for either species monitored by radio-telemetry techniques. During RSW operation, the trends did not exhibit clear differences among groups.

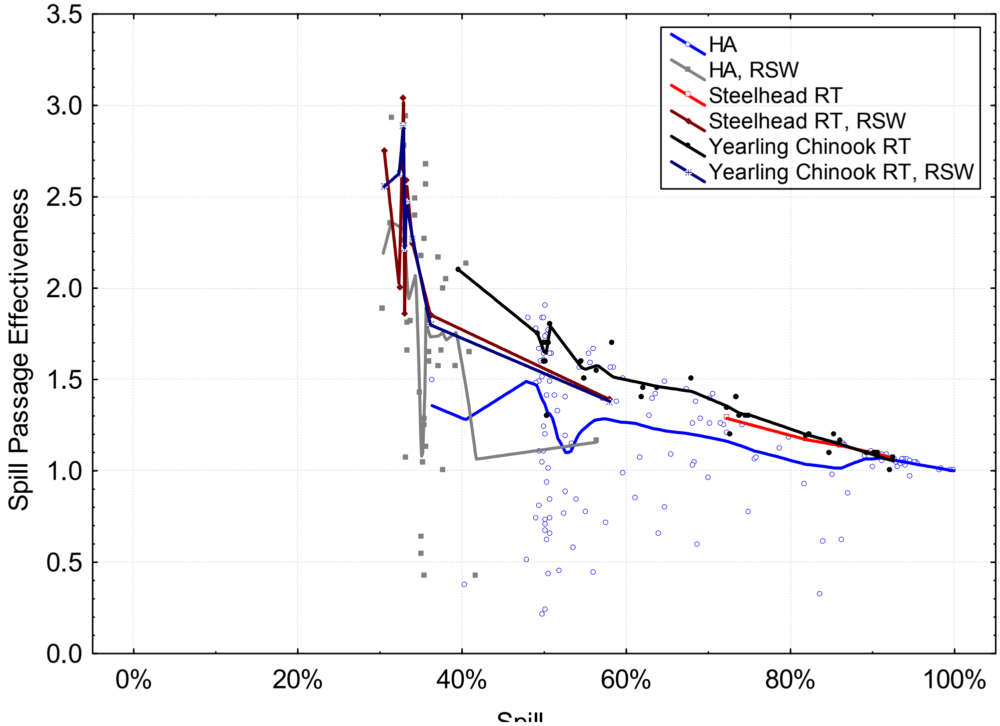

Figure 5.14. Spill Passage Effectiveness Plotted Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring. LOWESS fits illustrate trends, if any, in the available data.

Fitting exponential curves that typify trends in SPS to these spring passage groups added little to the information provided by the LOWESS curves (Figure 5.15). The exponential fits emphasize the influence of the RSW on SPS, but the lack of data at high and low spill proportions means that these curves were not well defined by the data.

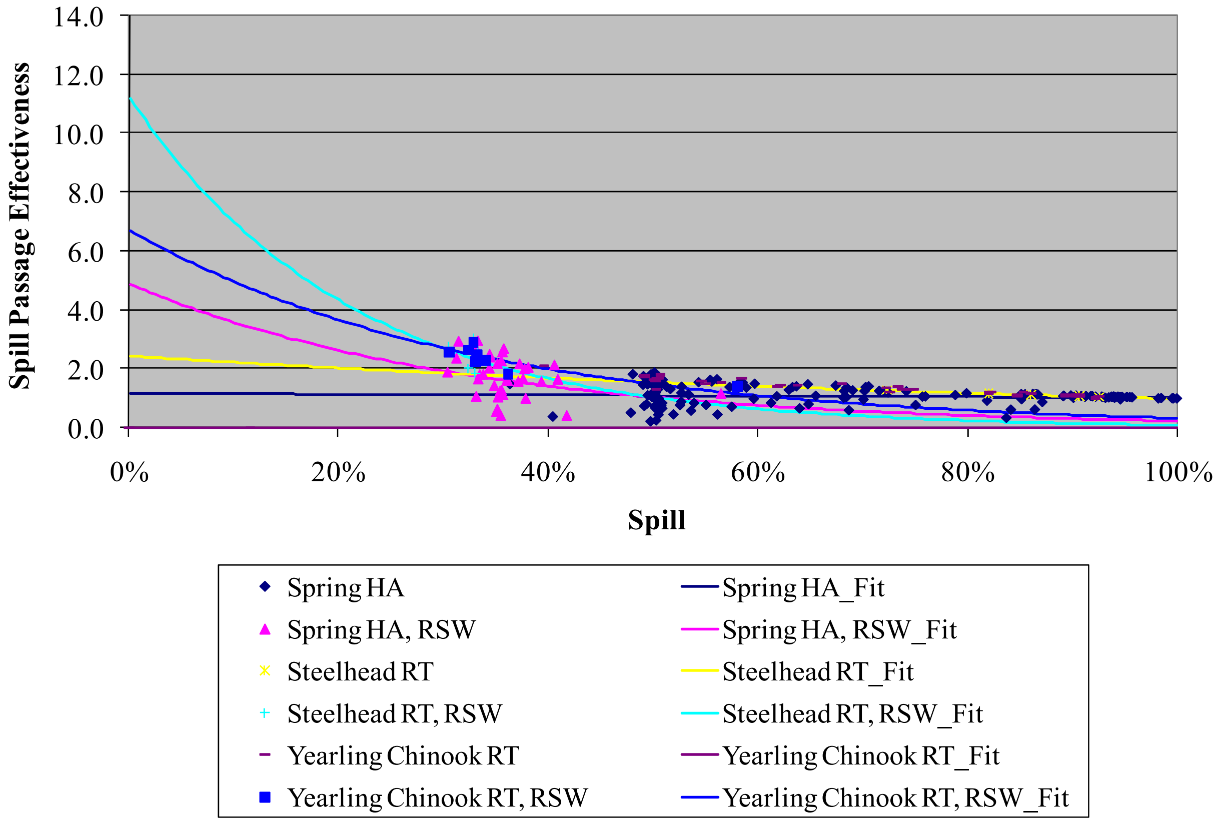

Figure 5.15. Exponential Fits to Spill Passage Effectiveness Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring

During the summer, the trends in SPS differed little from each other (Figure 5.16). The hydroacoustic results suggest a small increase in SPS during RSW operation, but the radio-telemetry results suggest that there was a decrease in SPS during RSW operation.

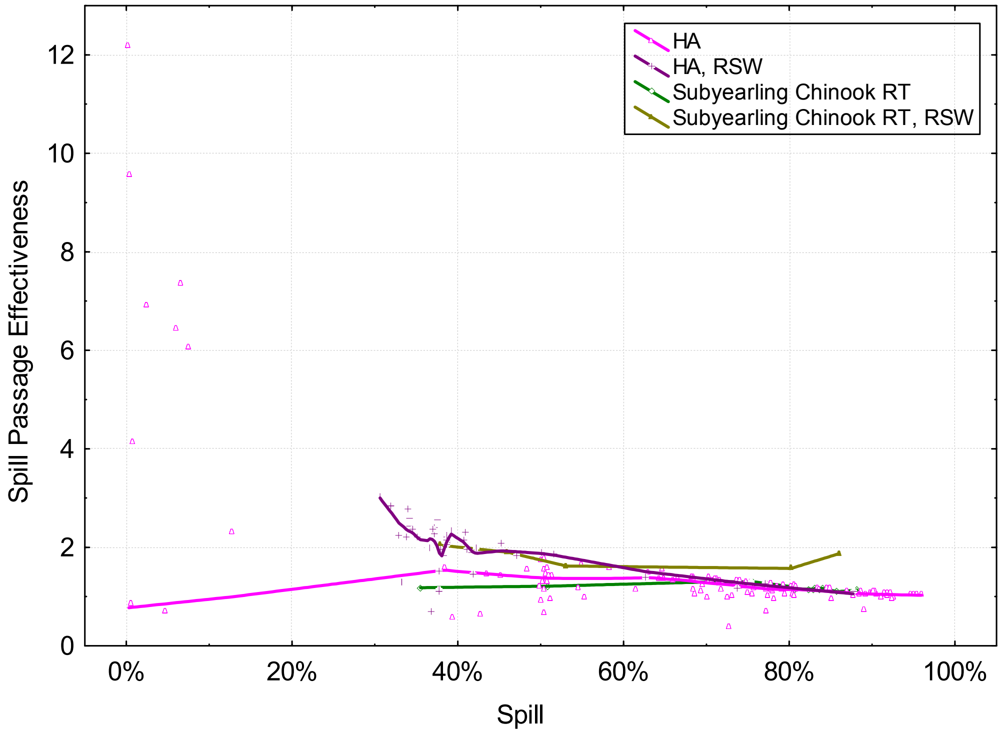

Figure 5.16. Spill Passage Effectiveness Plotted Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer. LOWESS fits illustrate trends, if any, in the available data.

The trends in SPS revealed by exponential fits to the summer radio-telemetry data suggest that RSW operations decreased SPS (Figure 5.17). The trends in hydroacoustic results indicated very little influence of the RSW on SPS. The trends in SPS across available studies leave much uncertainty about the contribution of the RSW to spill passage.

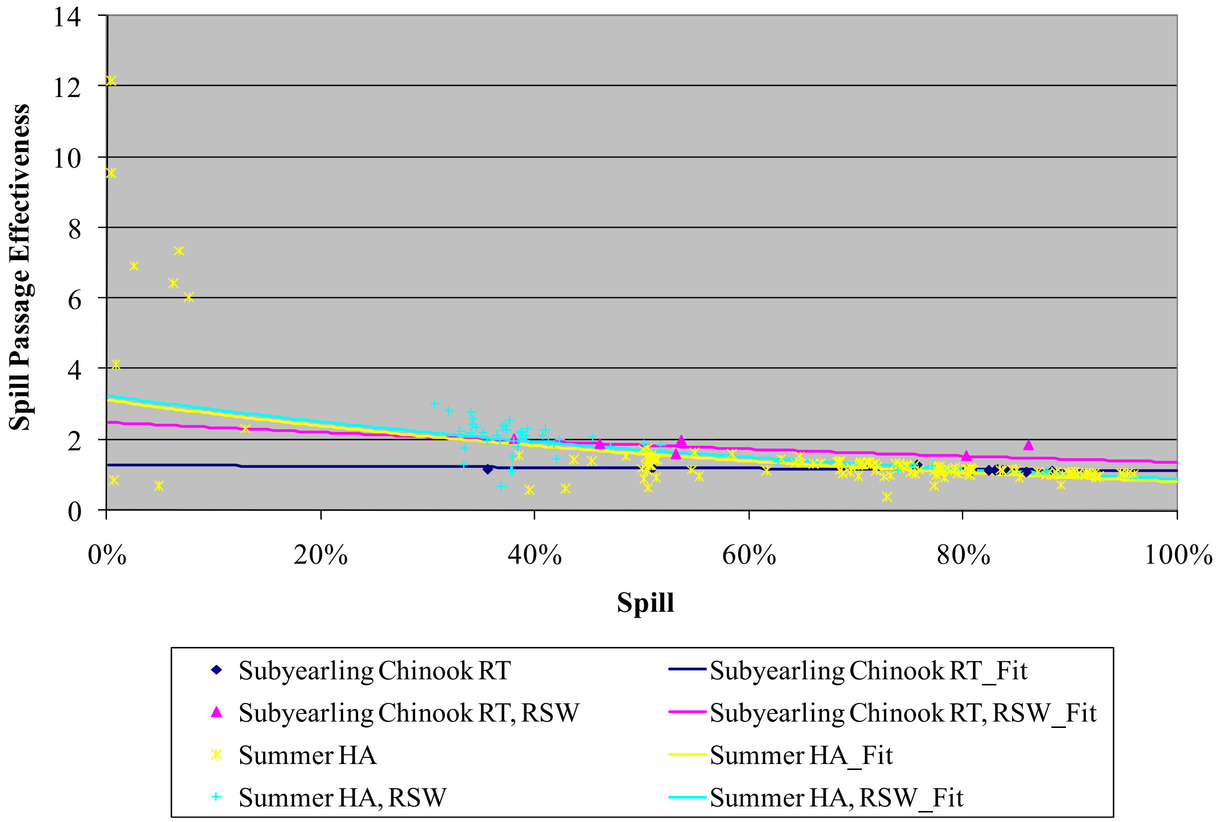

Figure 5.17. Exponential Fits to Spill Passage Effectiveness Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer

5.2.3 Effects of Spill on Project Fish-Passage Efficiency

Estimates of fish passage efficiency for Ice Harbor Dam were high for all treatment conditions tested (Table 5.4). The only treatment conditions with an estimated FPE of less than 90% were a no-spill treatment tested in the summer of 2003, when the FPE was 87.7% and for fish passing during >60% spill in 1997 at 83.0%.

Table 5.4. Estimate of Fish Passage Efficiency at Ice Harbor Dam

Year	Spill Treatment	Yearling Chinook (RT)	Steelhead (RT)	Spring Run at Large (HA)	Subyearling Chinook (RT)	Summer Run at Large (HA)	Source
1997	<40% Spill	–	–	–	100	–	Eppard et al. 1998
	40–50% Spill	–	–	–	90.0	–	
	50–60% Spill	–	–	–	100	–	
	>60% Spill	–	–	–	83.0	–	
1999	Not Reported	97.1	–	–	–	–	Eppard et al. 2000
2001	BiOp Spill	73.0	–	–	–	–	Axel et al. 2003
	Zero Spill	68.0	–	–	–	–	
2003	BiOp Spill	97.5	–	97.4	–	96.9	Eppard et al. 2005c; Moursund et al. 2004
	50% Spill	90.0	–	94.3	–	92.7	
	Bulk Spill	–	–	–	–	98.8	
	Zero Spill	–	–	–	–	87.7	
2004	Bulk Spill	98.6	100.0	–	94.8	–	Eppard et al. 2005a
	Flat Spill	94.9	99.0	–	97.0	–	
2005	Bulk Spill	99.6	99.2	97.5	99.4	98.9	Axel et al. 2007a; Moursund et al. 2007; Ogden et al. 2007
	RSW Spill	93.3	97.8	97.6	95.1	97.8	
2006	BiOp Spill	96.3	98.9	–	98.2	–	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill	92.5	97.8	–	–	–	

– = Estimates not available due to insufficient fish or no study conducted.

Figure 5.18 reveals a general trend of increasing FPE with increasing spill for spring migrating fish. When spill is zero, FPE is equivalent to FGE.

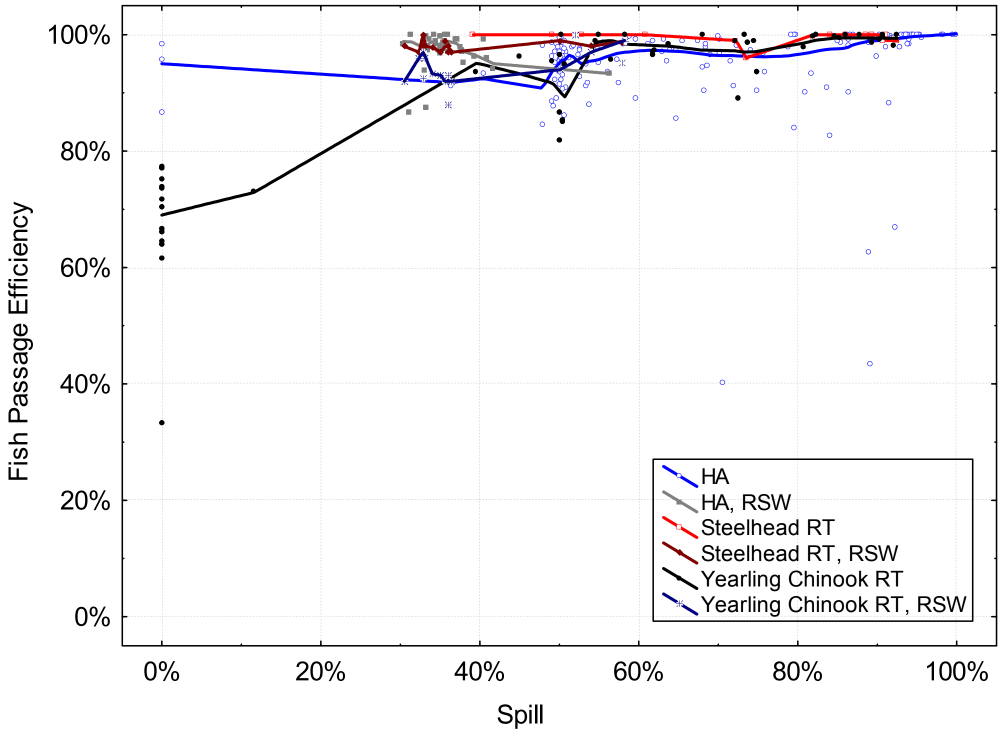

Figure 5.18. Fish Passage Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring. LOWESS fits illustrate trends, if any, in the available data.

During the summer, hydroacoustics estimated FPE to be nearly 90% in the absence of spill and the LOWESS fit suggested a consistent increase with increasing spill. No radio-telemetry estimates were available at low spill proportions, and it was more difficult to observe a trend.

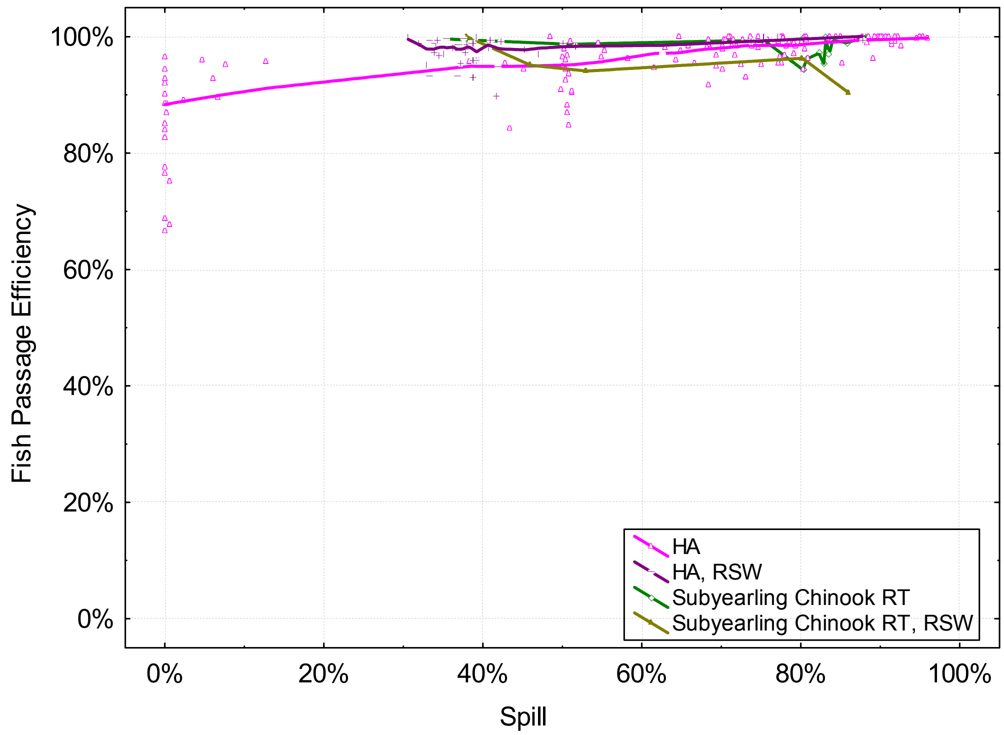

Figure 5.19. Fish Passage Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer. LOWESS fits illustrate trends, if any, in the available data.

5.2.4 Synthesis and Conclusions about Project-Wide Passage Metrics

Trends in fish passage with spill at Ice Harbor Dam were typical of trends at other Snake and Columbia river dams. Increasing spill increased SPE and FPE, but decreased SPS. The lack of overlap in spill proportion for conditions with and without the RSW operating prevented a clear evaluation of the influence of the RSW on fish passage. If RSW performance is a critical determinant of future management actions, it may be necessary to design studies to control other factors while evaluating that performance.

5.3 Fish Guidance Efficiency of Screens

Fish guidance efficiency, the proportion of fish entering the turbine intake that are diverted into the JBS by the intake screens, was estimated in hydroacoustic and radio-telemetry studies (Table 5.5). FGE estimates for steelhead typically exceeded 90%, and were typically between 70 and 80% for yearling Chinook salmon. Hydroacoustic estimates including both species were intermediate between the two. The FGEs for subyearling Chinook salmon passing during the summer varied between 50.0 and 62.5% in radio-telemetry studies. Summer hydroacoustic estimates of FGE were notably higher, ranging from 77.8 to 93.2%.

Table 5.5. Estimates of Fish Guidance Efficiency at Ice Harbor Dam

Year	Spill Treatment	Yearling Chinook Salmon (RT)	Steelhead (RT)	Spring Run at Large (HA)	Subyearling Chinook Salmon (RT)	Summer Run at Large (HA)	Source
1997	Not Reported	–	–	–	50.0	–	Eppard et al. 1998
1999	Not Reported	70.0	90.0	–	50.0	–	Ferguson et al. 2005
2001	Zero Spill[(a)]	67.7	–	–	–	–	Axel et al. 2003
2003	BiOp Spill	–	–	85.1	–	81.5	Moursund et al. 2004
	50% Spill	–	–	85.6	–	77.8	
	Bulk Spill	–	–	–	–	93.2	
	Zero Spill	–	–	–	–	87.7	
2004	Bulk Spill	87.0	100.0	–	–	–	Axel et al. 2005; Eppard et al. 2005a
	Flat Spill	79.1	96.0	–	–	–	
2005	Bulk Spill	72.2	73.7	67.7	62.5	84.3	Axel et al. 2007a; Moursund et al. 2007; Ogden et al. 2007
	RSW Spill	70.0	90.6	92.5	61.5	89.1	
2006	BiOp Spill	79.9	91.9	–	70.4	–	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill	70.6	94.7	–	–	–	

(a) Zero spill with the exception of spill on 19 May 2001 during emergency release.
– = Estimate not available due to insufficient fish detected or no study conducted.

FGE estimates across a wide range of spill proportions during the spring showed a general trend of decreasing FGE with increasing spill (Figure 5.20). The limited overlap of spill proportions among operations with and without an RSW operating prevents a clear evaluation of whether the RSW exerted an influence on FGE. The variation in FGE at higher spill proportions reflects the increasing uncertainty of those estimates based on smaller numbers of fish passing the powerhouse.

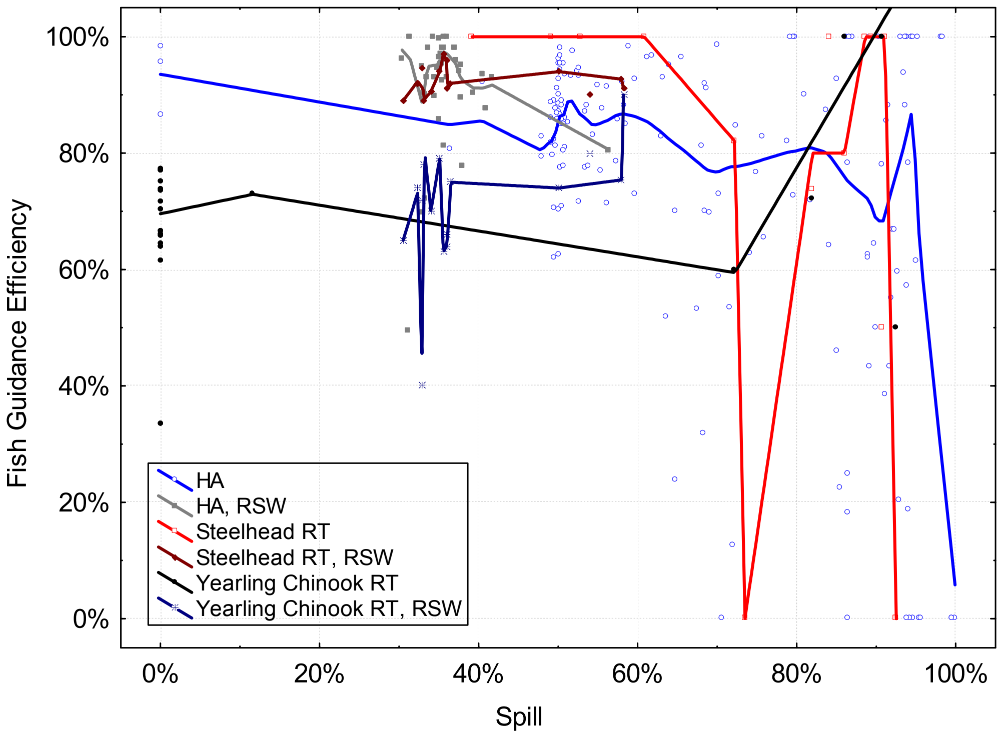

Figure 5.20. Fish Guidance Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Spring. LOWESS fits illustrate trends, if any, in the available data.

During the summer, LOWESS trends in FGE were less consistent across the range of spill proportions (Figure 5.21). The available data do not reveal an obvious influence of RSW operation on FGE.

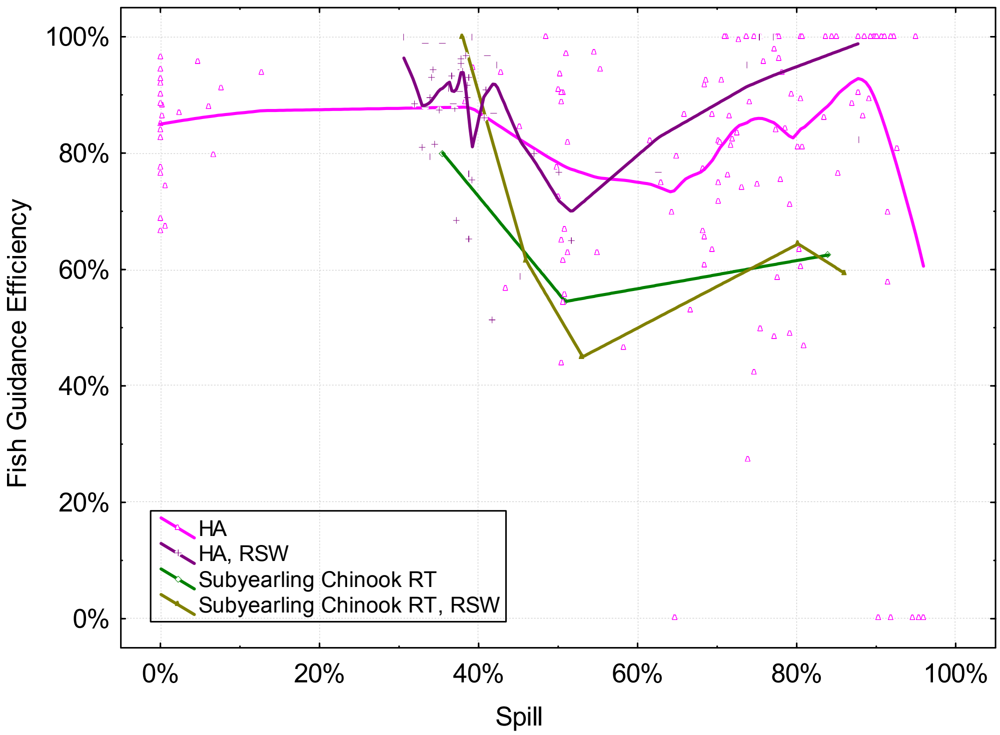

Figure 5.21. Fish Guidance Efficiency Versus Spill Proportion for Fish Passing Ice Harbor Dam During the Summer. LOWESS fits illustrate trends, if any, in the available data.

In general, FGE appeared to decline with increasing spill at Ice Harbor Dam. Such a trend would reduce the gains in FPE with increasing spill that might be expected from gains in spill efficiency. High spill proportions may attract a greater proportion of fish that would otherwise have been guided into the bypass than of fish that would otherwise pass through the turbines. The limited variety of operation of the RSW, relative to operation without the RSW, prevents a clear evaluation of whether RSW operation influences FGE.

5.4 Surface Flow Outlets

Surface flow outlet is a term that encompasses a diverse class of passage structures that allow surface water to pass over a structure, rather than under a regulating gate. The RSW at Ice Harbor Dam is a surface flow outlet designed for fish passage and installed at the spillway in spillbay 2. Passage at the RSW is combined with passage at the remainder of the spillway when evaluating overall spillway performance. Here, RSW performance is evaluated separately in relation to the dam as a whole.

5.4.1.1 The Efficiency and Effectiveness of the RSW

Evaluations of the passage performance of the RSW in 2005 revealed that it passed a high proportion of fish (Table 5.6). The effectiveness of the RSW was estimated to exceed 3.0 regardless of species or monitoring method. This indicates that the RSW passes a more than three times greater proportion of fish than proportion of water. Such high effectiveness values for the RSW suggest that fish prefer it over other routes and are not simply following bulk flow.

Table 5.6. Estimates of Surface Outlet Passage Efficiency (SOE) and Effectiveness (SOS) at Ice Harbor Dam. Source: Axel et al. 2007a; Axel et al. 2007b; Ham et al. 2007; Moursund et al. 2004; Ogden et al. 2007; Ogden et al. 2008

		Yearling Chinook (RT)		Steelhead (RT)		Spring Run at Large (HA)		Subyearling Chinook (RT)		Summer Run at Large (HA)	
Year	Treatment	SOE	SOS	SOE	SOS	SOE	SOS	SOE	SOS	SOE	SOS
2005	RSW Spill	29.0%	3.15	47.0%	5.09	28.4%	5.30	60.0%	3.40	38.4%	3.20
2006	BiOp Spill	33.1%	6.02	30.9%	5.56	–	–	68.0%	4.59	–	–
	30–40% Spill	51.3%	7.77	37.5%	5.68	–	–	–	–	–	–

– = Estimates not available due to insufficient fish or no study conducted.

5.4.2 Effect of Percent Flow on Surface Outlet Passage Efficiency

The proportion of total flow passing over the RSW was typically less than 20%, but the proportion of fish passing over the RSW was often greater than 50% (Figure 5.22). LOWESS trends indicate that SOE increased rapidly as the proportion of flow passing over the RSW increased. Because flow passing over the RSW is relatively constant due to narrow limits on forebay elevations during the fish passage season, the primary reason that the proportion of flow passing over the RSW would increase is a decrease in total flow. The typically lower flows of summer result in a greater proportion of total flow passing over the RSW.

When logit-logit curves are fit to SOE, the trend for spring hydroacoustic estimates is intermediate between the trends in radio-telemetry estimates for yearling Chinook salmon and steelhead (Figure 5.23). The trend for summer hydroacoustic estimates suggests a lower SOE at a given RSW flow proportion than does the trend for radio-telemetry estimates for subyearling Chinook salmon. The reader is cautioned to note that because only summary values were reported for SOE in the 2005 radio-telemetry studies, the corresponding logit-logit curves are defined by very few data points. Although these curves are intended to provide only informal visual comparisons, the limited data upon which they are based should be taken into account.

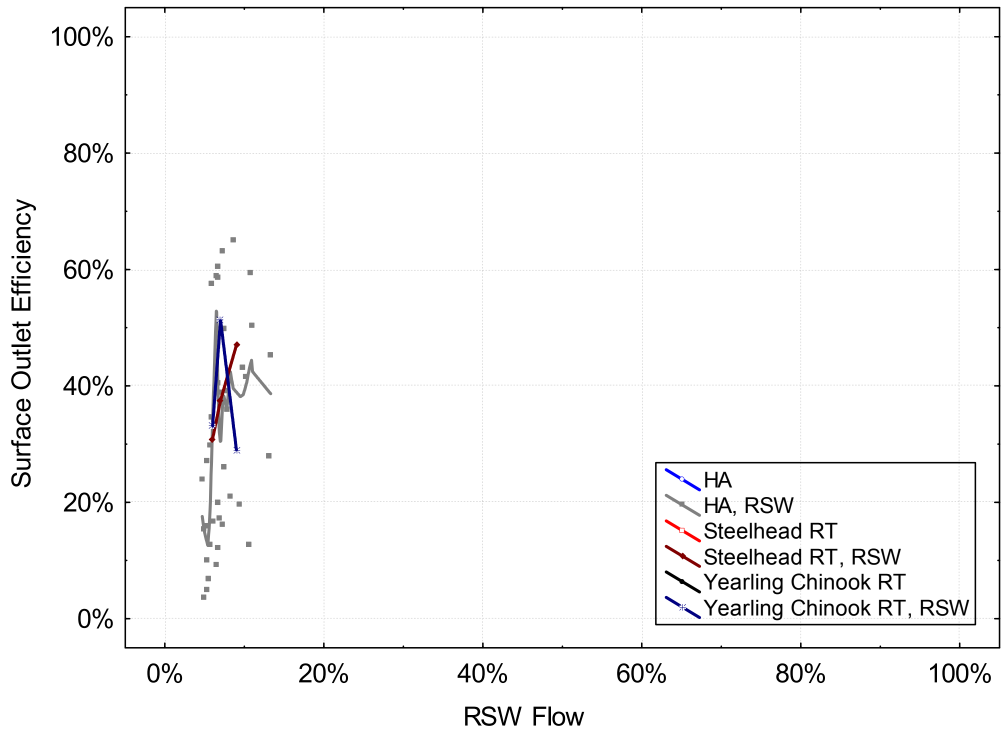

Figure 5.22. Surface Outlet Efficiency Versus RSW Flow Proportion for Fish Passing Ice Harbor Dam in the Spring. LOWESS fits illustrate trends, if any, in the available data.

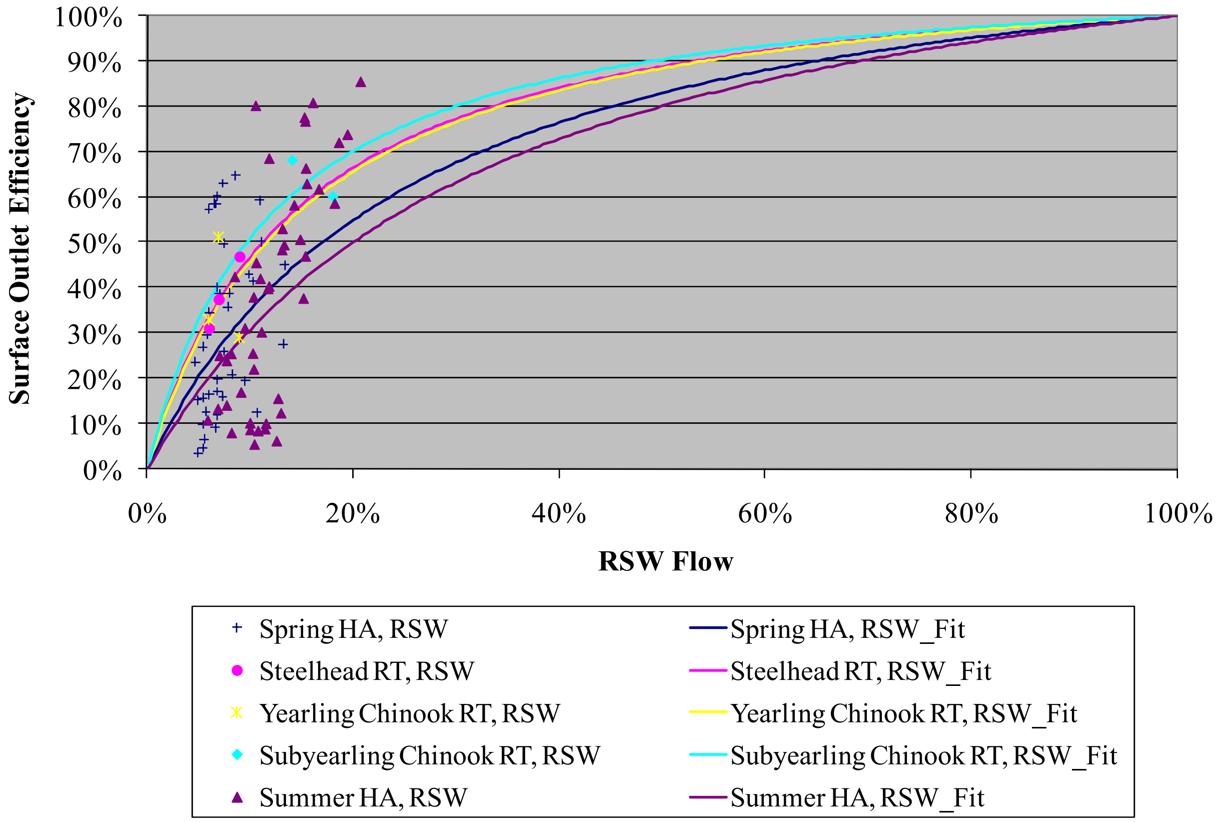

Figure 5.23. Curves Fit to Surface Outlet Efficiency Versus RSW Flow Proportion for Fish Passing Ice Harbor Dam in 2005

During the summer, SOE increased rapidly as RSW flow proportions increased within a narrow range (Figure 5.24). The few radio-telemetry estimates of SOE in the summer were similar to hydroacoustic estimates at a similar RSW flow proportion.

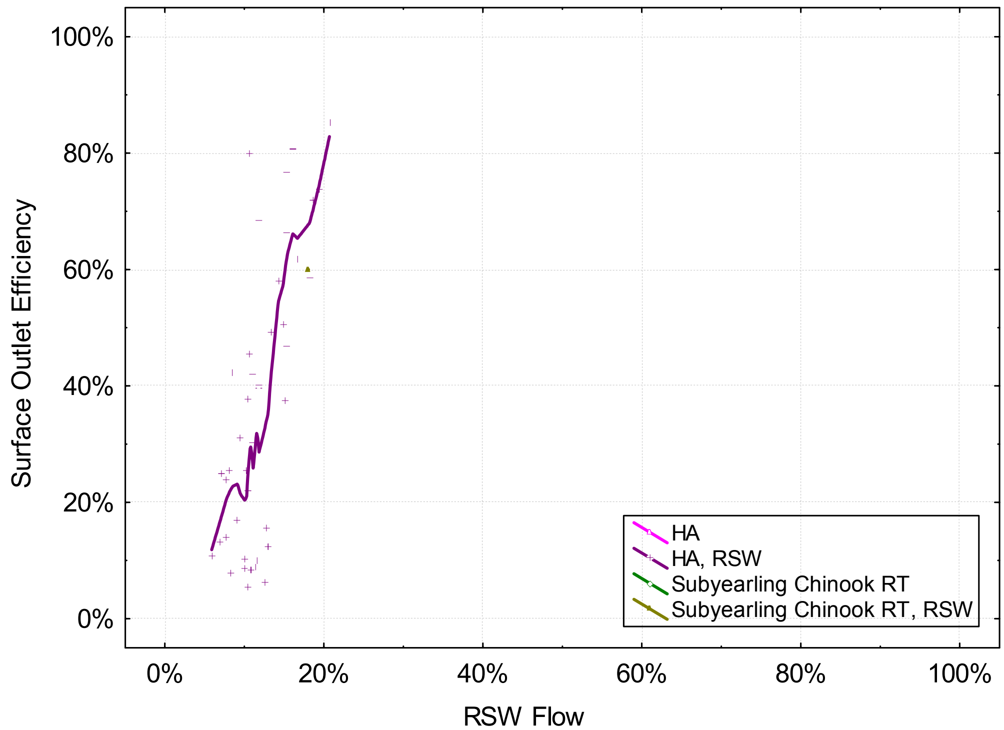

Figure 5.24. Surface Outlet Efficiency Versus RSW Flow Proportion for Fish Passing Ice Harbor Dam in the Summer. LOWESS fits illustrate trends, if any, in the available data.

5.4.3 Effect of Percent Flow on Surface-Flow-Outlet Effectiveness

The effectiveness of the RSW would be expected to increase exponentially as spill proportion decreased. The limited range of data does not provide evidence of such a trend, at least when the LOWESS fits are examined (Figure 5.25). Operations that result in the RSW flow making up a much larger or much smaller proportion of total flow would likely be rare, and they probably would not represent viable options for fisheries management. The distribution of SOS values for subyearling Chinook salmon in Figure 5.26 suggest that the RSW performs with relatively high effectiveness across the variety of conditions tested, but the trend is not consistent with the expectation that SOS will increase as RSW flow proportion decreases.

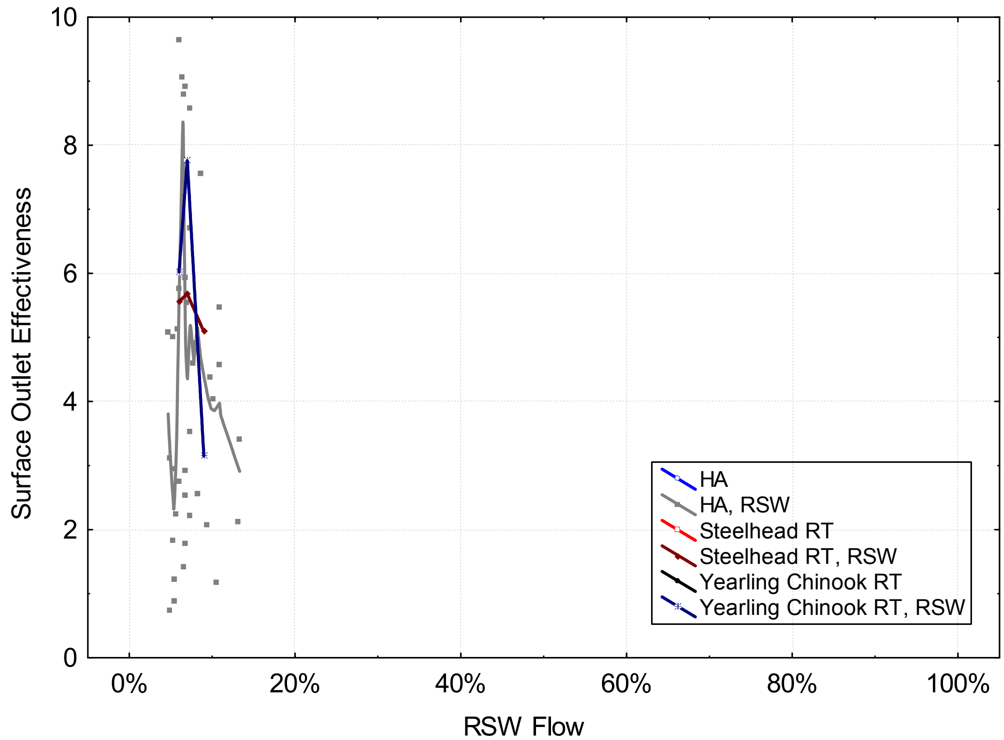

Figure 5.25. Surface Outlet Effectiveness Versus RSW Flow Proportion for Fish Passing Ice Harbor Dam in the Spring. LOWESS fits illustrate trends, if any, in the available data.

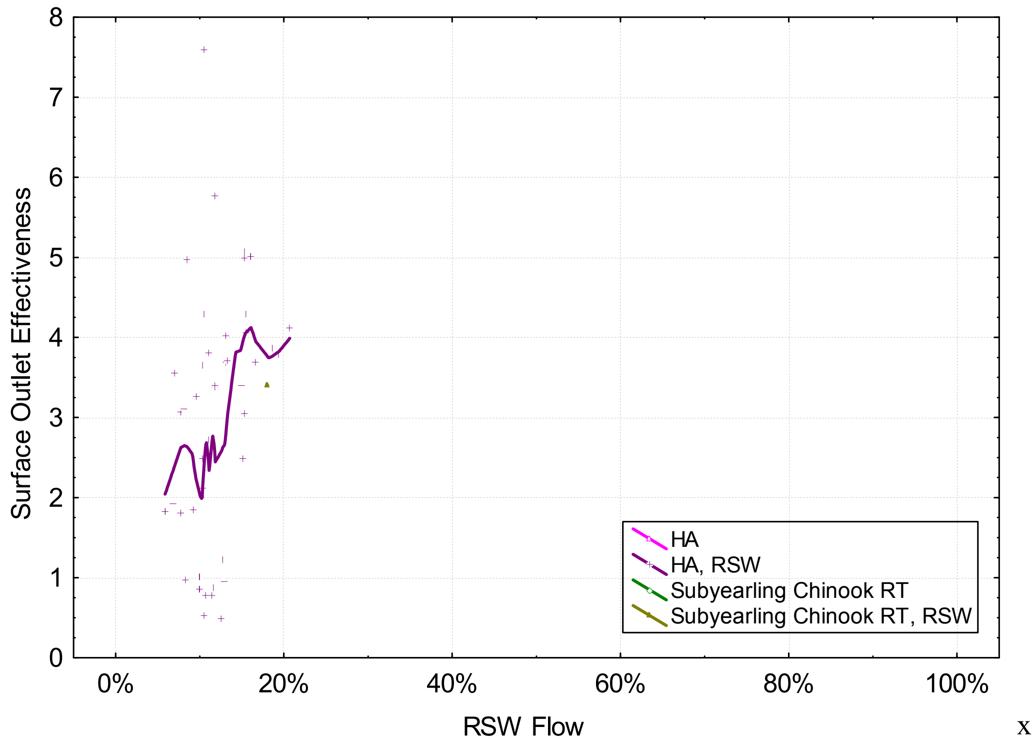

Figure 5.26. Surface Outlet Effectiveness Versus RSW Flow Proportion for Fish Passing Ice Harbor Dam in the Summer. LOWESS fits illustrate trends, if any, in the available data.

5.4.4 Synthesis and Conclusions About Fish Passage at Surface Flow Outlets

The RSW was found to be an attractive passage route, as evidenced by high values for efficiency and effectiveness. When simple logit-logit trends were fit to RSW passage proportions versus RSW flow proportions, the trends were similar to those for the entire spillway. A critical difference is that the RSW was operated at much lower proportions of total flow. Efficiency increased rapidly as RSW flow proportions increased. Although the RSW operations at higher spill proportions would likely be rare, the efficiency would be expected to increase slowly as RSW flow proportions increased further.

6.0 Juvenile Salmonid Survival

Juvenile salmonid survival studies conducted at Ice Harbor Dam evaluated relative dam survival, relative spillway survival, relative turbine survival, relative JBS survival, and relative RSW survival. Additional studies evaluated the influence of predation on juvenile salmonid survival.

6.1 Dam Passage Survival

Relative dam survival at Ice Harbor Dam has been estimated for a number of studies across multiple years. Annual studies contrasted survival rates between experimental treatments that varied in the proportion of spill, the pattern of spill, and the configuration of the dam (i.e., whether or not the RSW was operated). Variation among spill treatments and variation in flow levels among years provide a variety of conditions across which to analyze variation in survival estimates.

When yearling Chinook salmon survival estimates are plotted versus spill proportion, it becomes obvious that the ranges of spill proportion for the major categories of spill patterns (bulk, flat, or RSW) have very little in common (Figure 6.1). Therefore, spill operations and spill patterns are confounded, preventing a clear evaluation of which factor is influencing survival.

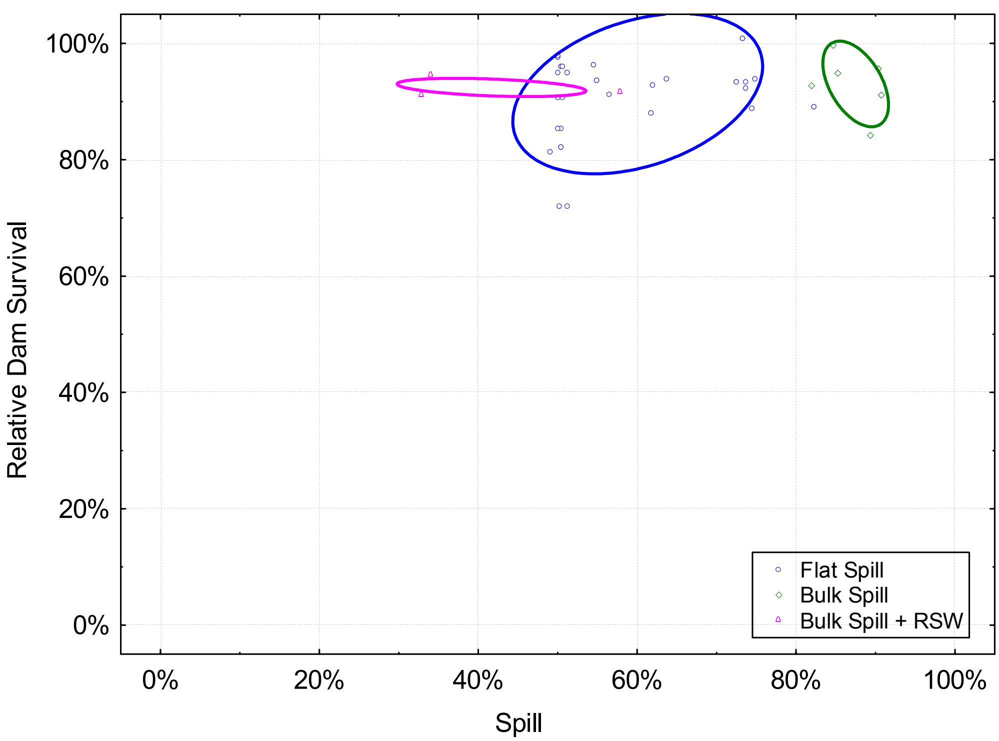

Figure 6.1. Relative Dam Survival Versus Mean Spill Proportion at Ice Harbor Dam for Yearling Chinook Salmon. Ellipses indicate 95% of the range of x and y values.

The grouping of survival estimates into spill pattern groups revealed less confounding for subyearling Chinook salmon (Figure 6.2). Bulk and flat spill treatments were tested across similar ranges of spill percentage. In general, flat spill appeared to result in lower dam survival rates than did bulk spill, but there was considerable overlap. Treatments including RSW operation included lower proportions of spill from both bulk and flat spill groups, but survivals remained high.

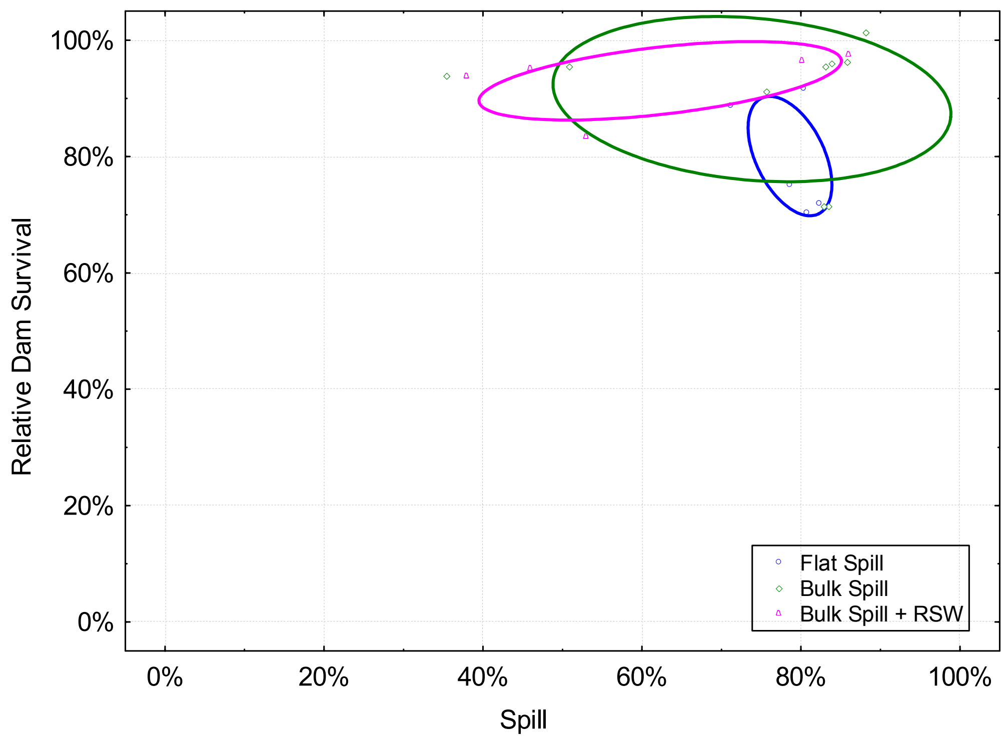

Figure 6.2. Relative Dam Survival Versus Mean Spill Proportion at Ice Harbor Dam for Subyearling Chinook Salmon. Ellipses indicate 95% of the range of x and y values.

6.2 Route-Specific Survival

It is valuable to know the survival rates for fish passing through each type of passage route. This information, in combination with passage relationships, can reveal operational scenarios that will increase the overall survival rates for fish passing the dam. Table 6.1 shows the routes for which survival was measured in studies of yearling Chinook salmon. The highest survival rates were found for the JBS, followed by the spillway and the RSW. Too few radio-tagged fish typically pass through turbines at Ice Harbor Dam to allow the estimation of turbine survival. In 2003, a PIT-tag study released fish into turbine intakes and 87.1% survived.

Survival rates for the spillway, RSW, and JBS, were all high for steelhead (Table 6.2). Turbine survival was not measured for steelhead.

Survival rates of subyearling Chinook salmon passing over the RSW or spillway were high, except in 2000 (Table 6.3). Turbine survival rates were lower than other routes, but were still around 90%.

Table 6.1. Estimates of Route-Specific Survival for Yearling Chinook Salmon at Ice Harbor Dam

Year	Spill Treatment	Dam Survival (95% CI)	Spillway Survival (95% CI)	RSW Survival (95% CI)	JBS Survival (95% CI)	Turbine Survival (95% CI)	Source
2000	BiOp Spill	–	97.8 (94.1-101.8)	–	–	–	Eppard et al. 2002
2001	Zero Spill	93.6 (89.5-97.7)	–	–	99.6 (94.7-104.6)	–	Axel et al. 2003
2003	BiOp Spill	94.8 (92.3-97.2)	–	–	–	–	Eppard et al. 2005c
	50% Spill	92.7 (87.5-98.3)	–	–	–	–	
2004	Bulk Spill	93.0 (86.4-99.7)	97.4 (93.6-101.1)	–	–	–	Eppard et al. 2005a
	Flat Spill	89.5 (84.5-94.5)	95.2 (93.0-97.4)	–	–	–	
2005	RSW Spill	94.5 (92.5-96.5)	95.8 (93.7-97.9)	–	99.7 (96.8-102.7)	–	Axel et al. 2007a
	Bulk Spill	92.8 (90.7-95.0)	97.1 (95.2-99.0)	97.0 (94.2-99.9)		–	
2006	BiOp Spill	91.6 (89.8-93.4)	96.4 (94.8-98.8)	95.5 (94.7-96.3)	97.3 (94.4-100.2)	97.3 (94.4-100.2)	Axel et al. 2007b
	30–40% Spill	91.2 (89.0-93.4)	95.7 (93.7-97.7)	94.7 (92.1-97.3)	98.3 (95.5-101.1)	98.3 (95.5-101.1)	

CI = confidence interval
– = no data or not reported

Table 6.2. Estimates of Route-Specific Survival for Steelhead at Ice Harbor Dam

Year	Spill Treatment	Dam Survival (95% CI)	Spillway Survival (95% CI)	RSW Survival (95% CI)	JBS Survival (95% CI)	Source
2004	Bulk Spill	87.0 (83.8-90.2)	97.7 (94.8-100.7)	–	–	Eppard et al. 2005a
	Flat Spill		97.7 (92.6-102.8)	–	–	
2005	RSW Spill	90.8 (87.7-93.9)	98.0 (95.1-101.0)	98.5 (92.9-101.6)	101.5 (97.6-105.5)	Axel et al. 2007a
	Bulk Spill	93.2 (90.0-96.4)	100.0 (97.2-102.7)	–		
2006	BiOp Spill	94.1 (91.9-96.3)	100.9 (99.1-102.7)	98.4 (95.4-101.4)	101.0 (98.2-103.8)	Axel et al. 2007b
	30–40% Spill	90.0 (86.8-93.2)	101.7 (99.3-104.1)	101.7 (98.9-104.5)	99.7 (96.3-103.1)	

CI = confidence interval
– = no data or not reported

Table 6.3. Estimates of Route-Specific Survival for Subyearling Chinook Salmon at Ice Harbor Dam

Year	Spill Treatment	Dam Survival (95% CI)	Spillway Survival (95% CI)	RSW (95% CI)	JBS (95% CI)	Turbine (95% CI)	Source
2000	BiOp Spill	–	88.5 (85.6-91.5)	–	–	–	Eppard et al. 2002
2003	Bulk Spill	–	96.4 (90.5-102.6)	–	99.7 (95.9-103.6)	91.0 (85.4-97.0)	Absolon et al. 2005
	Zero Spill	–	–	–	–	88.6 (79.9-98.2)	
2004	Bulk Spill	86.2 (69.2-107.5)	97.2 (90.3-104.5)	–	–	–	Eppard et al. 2005a
	Flat Spill	84.6 (73.6-97.2)	93.3 (88.2-98.6)	–	–	–	
2005	RSW Spill	95.1 (87.0-104.0)	98.9 (94.5-104.0)	99.7 (96.0-104.0)	98.8 (91.6-106.1)	–	Ogden et al. 2007
	Bulk Spill	96.0 (92.0-97.8)	100 (98.0-102.0)	–		–	
2006	BiOp Spill	95.2 (93.8-96.7)	98.8 (95.0-102.5)	98.8 (92.5-103.5)	–	–	Ogden et al. 2008

CI = confidence interval
– = no data or not reported

6.3 Predation

Avian predation has been documented in the reach between Ice Harbor and McNary dams where piscivorous bird colonies are found on several islands in the McNary pool. Monitoring efforts have focused on evaluating predation by the Caspian tern population on Crescent Island, located approximately 12.9 km downstream from the mouth of the Snake River. Because PIT-tag detectors were not consistently available at Ice Harbor until 2005, most of the predation information is available for the Lower Monumental to McNary dam reach. Faulkner et al. (2007) noted that estimates for survival of steelhead and yearling Chinook salmon were similar in the reach from Lower Monumental and Ice Harbor dams, but were about 7% lower for steelhead than for yearling Chinook salmon in the reach from Ice Harbor Dam to McNary Dam, which is consistent with the possibility that greater predation in the reach between Lower Monumental and McNary dams occurs below Ice Harbor Dam. Crescent Island Caspian terns were identified as the primary predators, but there are also colonies of American white pelicans, cormorants, and gulls in the McNary pool.

PIT tags and radio tags from fish detected at Lower Monumental Dam were found on these islands in the McNary pool and provide a minimum estimate of predation rate. Predation estimates are affected by other factors, such as differential transport of tagged versus untagged fish, tag deposition at points other than on the islands, and incomplete detection of deposited tags.

Table 6.4 reveals a wide variation in the percentage of PIT-tagged yearling Chinook salmon or steelhead found at bird colonies in the McNary pool. Low flow years such as 2001, 2002, and 2004, appear to result in relatively high rates of predation for steelhead and a relative increase in the rate of predation for yearling Chinook salmon. Estimates of predation rates in the reach from Ice Harbor Dam to McNary Dam for radio-tagged yearling Chinook salmon were often higher than for PIT-tagged fish in the longer reach from Lower Monumental Dam to McNary Dam. We do not have information about the relative probability of detecting radio tags or PIT tags on the bird colonies, but it seems reasonable to assume that there could be differences in detection probability. Such a difference in detection probability could help explain why radio-telemetry estimates of predation from Ice Harbor Dam to McNary Dam can exceed the PIT-tag estimates of predation over the longer reach from Lower Monumental Dam to McNary Dam.

Table 6.4. Percentage of PIT-Tagged Juvenile Salmon Detected at Lower Monumental Dam and Recovered from McNary Pool Bird Colonies

Species	2000	2001	2002	2003(a)	2004(b)	2005	2006	Report
				Lower Monumental Dam to McNary Dam				
Yearling Chinook Salmon	0.98	5.59	1.62	1.06	2.08	1.37	0.92	Faulkner et al. 2007
Steelhead	3.66	21.06	10.09	3.71	19.42	9.15	4.81	
Steelhead	–	–	–	–	20	–	–	Axel et al. 2005
				Ice Harbor Dam to McNary Dam				
Yearling Chinook Salmon, Radio-Tagged, Released to IHR Outfall	–	6.6	–	–	–	–	–	Axel et al. 2003
Yearling Chinook Salmon, Radio-Tagged, Released 5 km Above IHR	–	5.1	–	–	–	–	–	
Yearling Chinook Salmon, PIT-Tagged, Released 5 km Above IHR	–	3.9	–	–	–	–	–	
Yearling Chinook Salmon, Day & Night, PIT-Tagged	–	–	2.1	–	–	–	–	Eppard et al. 2005b
Yearling Chinook Salmon, Day & Night, Radio-Tagged	–	–	7.7	–	–	–	–	
Yearling Chinook Salmon, Day Release to Spillway, Radio-Tagged	–	–	9.2	–	–	–	–	
Yearling Chinook Salmon, Day Release to Tailrace, Radio-Tagged	–	–	7.4	–	–	–	–	
Yearling Chinook Salmon, Night Release to Spillway, Radio-Tagged	–	–	6.4	–	–	–	–	
Yearling Chinook Salmon, Night Release to Tailrace, Radio-Tagged	–	–	7.5	–	–	–	–	
Subyearling Chinook Salmon, Radio-Tagged, Released to IHR Forebay	–	–	–	–	3.7	–	–	Ogden et al. 2005
Subyearling Chinook Salmon, Radio-Tagged, Released to IHR Tailrace	–	–	–	–	5.0	–	–	
Steelhead	–	–	–	–	14	–	–	Axel et al. 2005

(a) Only the Crescent Island Caspian tern colony was sampled.
(b) Only Crescent and Foundation island bird colonies were sampled.
– = not estimated.
IHR = Ice Harbor Dam

If we ignore the potential biases introduced by different tagging techniques and detection probabilities of tags at bird colonies, the results for 2004 in Table 6.4 suggest that steelhead are most susceptible to predation, followed by subyearling and yearling Chinook salmon. Table 6.5 provides estimates for these three species plus sockeye, but with an adjustment for bias due to tag collision and detection efficiency. The rankings remain the same, with steelhead most susceptible followed by subyearling Chinook salmon and then yearling Chinook salmon. No predation was detected for sockeye, but the small numbers of tagged sockeye released may have been insufficient to detect predation.

Table 6.5. Estimated Predation Rates in 2004 by Crescent Island Terns on In-River PIT-Tagged Salmonid Smolts Detected at Lower Monumental Dam. Estimates adjusted for bias due to tag collision and detection efficiency. Source: Collis et al. (2006)

	Released In-River		Average Predation Rate[a]	
Species	Hatchery	Wild	Hatchery %	Wild %
Steelhead	41,784	32,150	10.8 (±5.5)	4.8 (±4.5)
Subyearling Chinook Salmon	36,455	1,995	0.8	0.0
Yearling Chinook Salmon	205,210	82,967	0.3 (±0.2)	0.2 (±0.2)
Sockeye	4,714	616	0.0	0.0

(a) Standard deviation in parentheses.

6.4 Synthesis and Conclusions About Juvenile Salmonid Survival

Relative dam survival rates have been estimated for bulk, flat, and RSW spill treatments. Unfortunately, treatments for which survival was estimated often differed in both spill pattern and spill proportion during yearling Chinook salmon studies. The influence of the spill pattern was confounded with the influence of spill proportion within the available data. The situation was improved for bulk and flat spill treatments during subyearling Chinook salmon studies, but the influence of the RSW remained confounded with spill proportion.

At Ice Harbor Dam, survival studies for yearling Chinook salmon, steelhead, and subyearling Chinook salmon indicate that the JBS has the highest route specific survival rates (98.5–99.7%) of any route. The RSW and spillway were a close second (88.5–100%). That leaves turbine passage (at approximately 90%) as the route type with the lowest survival rate.

Of species studied, results suggest that steelhead were most susceptible to predation, followed by subyearling and yearling Chinook salmon. The percentage of radio tags found on piscivorous bird colonies did not agree in absolute levels with the percentages for PIT tags found, but both ranked species in the same order for susceptibility. Predation rates appeared to increase during low flow years, especially for steelhead. Predation rates for steelhead were sometimes as high as 20%, and these estimates have been presented as minimum values because some tags of fish that fall prey to bird predators are not found. These numbers suggest that important gains in the survival of juvenile steelhead are possible if management options can decrease susceptibility to predation.

7.0 Tailrace Egress Time

Tailrace egress times were measured from the last detection that defined the instant of passage to the first detection at a downstream location. Differences in tailrace egress times could indicate a change in conditions just downstream of the dam, but might also be a function of the distribution of fish among passage routes. Past studies included tests of differing spill proportions, of differing spill patterns, and of the operation of the RSW. Although statistically significant differences were rarely found, tailrace egress times were shorter for the treatment or diel period with a lower spill proportion in three out of four tests for yearling Chinook salmon (Table 7.1). Within years, lower spill proportions were associated with BiOp day spill in 2002, 50% spill in 2003, flat spill in 2004, and RSW spill in 2005. Tailrace egress times for steelhead were shorter during the treatment with a higher spill proportion in 2004, but not in 2005. Subyearling Chinook salmon exited the tailrace more quickly during the higher spill treatment during both 2004 and 2005. The tailrace egress times for yearling Chinook salmon during 2005 are unexpectedly short relative to other years. Although a change in downstream detection location was not noted for yearling Chinook salmon, the times are more similar to steelhead tailrace egress times, which depend upon detection 1 km downstream, rather than 2 km downstream. Overall, the relationship of tailrace egress times with operations and configurations was not clear.

Table 7.1. Tailrace Egress Times (minutes) for Fish Passing Ice Harbor Dam

Year	Treatment	Yearling Chinook	Steelhead	Subyearling Chinook	Source
2001	Zero Spill[a]	9.30[b]	–	–	Axel et al. 2003
2002	BiOp Day Spill	27.00[c]	–	–	Eppard et al. 2005b
	BiOp Night Spill	32.00[c]	–	–	
2003	BiOp Spill	21.00[c]	–	–	Eppard et al. 2005c
	50% Spill	22.00[c]	–	–	
2004	Bulk Spill	23.00[c]	3.00[d]	4.40[e]	Eppard et al. 2005a; Ogden et al. 2005
	Flat Spill	22.00[c]	4.40[d]	5.90[e]	
2005	RSW Spill	2.80[c]	2.50[d]	4.22[e]	Axel et al. 2007a
	Bulk Spill	3.10[c]	3.10[d]	3.19[e]	
2006	BiOp Spill	8.52[d]	8.52[d]	10.7[f]	Axel et al. 2007b; Ogden et al. 2008
	30–40% Spill	8.58[d]	9.60[d]	–	

(a) Spill only on May 19.
(b) Downstream detection location not specified.
(c) Downstream detection at Goose Island, distance approximately 2 km from the dam.
(d) Downstream detection at telemetry transect approximately 1 km from the dam.
(e) Downstream detection at tailrace exit transect, distance not specified.
(f) Not defined
– = Insufficient fish detected or data not provided.

8.0 Special Studies

Direct injury studies typically are short-term evaluations of specific conditions or structures, rather than evaluations of conditions across a passage season. At Ice Harbor Dam, direct injury studies (using balloon-tagged fish and Sensor Fish devices) were conducted from 2003 through 2006 to test the impact of RSW operation, spill volume, spill patterns, deflector elevation, and tailwater elevations on fish approaching and passing the dam at various depths in the water column (Carlson et al. 2008; Carlson and Duncan 2004; Normandeau Associates, Inc. 2004; Normandeau Associates, Inc. 2006; Normandeau Associates, Inc. and Skalski 2005; Normandeau Associates, Inc. and Skalski 2006).

In 1996, deflectors were installed at an elevation of 338 feet above msl at spillways 2 through 9 to mitigate TDG in the spill discharge as it entered the stilling basin. In 1998, deflectors were installed in spillbays 1 and 10, at an elevation of 334 feet above msl, approximately 4 feet lower than the other spillways. Direct injury tests evaluated the influence of those deflectors on fish injury in combination with an array of tailrace conditions. The RSW was installed in spillbay 2 prior to the 2005 fish passage season and a direct injury test was conducted prior to the 2005 fish passage season.

The results of direct injury and Sensor Fish studies conducted from 2003 to 2006 indicate that high spill volume per spillbay minimized the likelihood of injury events to Sensor Fish devices and juvenile yearling and subyearling Chinook salmon. As spill volume per bay was reduced, the rate and severity of injury increased. In contrast, the rate of mortality showed no significant increase with decreased spill volume per bay or increased rate of injury.

A test of tailrace conditions, characterized as plunging, skimming, or undulating flows, found no significant differences in injury rates among conditions tested.

Fish from the deepest release location at the RSW exhibited higher mortality than fish from the deepest release location at spillbay 3. Sensors released at the deepest release locations detected more events suggestive of injury or mortality. RSW and spillbay 3 injury and survival rates were comparable for fish released at other depths.

The common thread for injury studies at Ice Harbor Dam was the trend of higher injury rates for fish and greater indications of injurious conditions measured by sensors released at the deepest release locations. This trend has been interpreted to be a result of fish released at the greatest depths traveling nearer to the concrete, leading to greater rates and severity of injury than were found for fish released at mid or shallow depths.

9.0 Optimizing Juvenile Fish Passage Strategies at Ice Harbor Dam

The information required to optimize juvenile fish passage strategies at Ice Harbor Dam would include the expected influence of operations and configurations on fish approach, passage, egress, and survival. Analysis of past studies provided some of that information, but also identified data gaps.

9.1 The Safest Passage Routes

The JBS, RSW, and spillway all have relatively high survival rates. Operations and configurations that maintain high FPE values as well as favorable forebay and tailrace conditions should be effective at maintaining high dam survival rates at Ice Harbor Dam.

9.2 Possible Measures to Improve Survival

Measures to improve survival could include measures that affect the forebay, passage, egress, or the condition of the fish as they leave the dam. The high rates of avian predation during low flow years also provide an opportunity to improve survival if effective management actions can be identified.

9.2.1 Powerhouse

JBS survival rates are currently high, but the intake geometry at Ice Harbor Dam would not allow screens to be extended as much as has been done at Lower Granite Dam, for example. Future replacement of Ice Harbor Dam turbines provides an opportunity to increase turbine survival and achieve greater flexibility in achieving survival goals.

9.2.2 Spillway

Bulk spill appears to be effective in increasing spillway survival at Ice Harbor Dam. More study is needed to optimize the RSW and spill proportion to achieve low forebay residence times and good tailrace egress with high survival rates and high SPE.

9.3 Data Gaps

Studies of fish passage and survival at Ice Harbor Dam have focused on proportions of spill that are high, relative to other dams. This is due, in part, to the lack of collection for transportation at Ice Harbor dam. Future studies should consider whether a different range of spill might create better tailrace conditions and increase survival downstream of Ice Harbor, where fish in better condition might better evade predation by birds. If a promising condition can be found, it would require testing to confirm survival benefits.

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Appendix A

Treatment Tests at Ice Harbor Dam

Appendix A

Treatment Tests at Ice Harbor Dam

This appendix presents tables that detail the experimental treatments used during the juvenile fish migration at Ice Harbor Dam from 2000 through 2006.

Table A.1. 2003 Nominal Treatment Schedule at Ice Harbor Dam. Transition from spring to summer occurred on June 7.

Month	Day	Block	Test	Month	Day	Block	Test	Month	Day	Block	Test
April	23		BiOp	May	24	8	SP50	June	24	17	Bulk
April	24		BiOp	May	25	8	SP50	June	25	17	Bulk
April	25		BiOp	May	26	9	BiOp	June	26	17	Zero Spill
April	26	1	BiOp	May	27	9	BiOp	June	27	17	Zero Spill
April	27	1	SP50	May	28	9	SP50	June	28	18	Bulk
April	28	2	BiOp	May	29	9	SP50	June	29	18	Bulk
April	29	2	BiOp	May	30	10	BiOp	June	30	18	Zero Spill
April	30	2	SP50	May	31	10	BiOp	July	1	18	Zero Spill
May	1	2	SP50	June	1	10	SP50	July	2	19	Bulk
May	2	3	BiOp	June	2	10	SP50	July	3	19	Bulk
May	3	3	BiOp	June	3	11	BiOp	July	4	19	Zero Spill
May	4	3	SP50	June	4	11	BiOp	July	5	20	Bulk
May	5	3	SP50	June	5	11	SP50	July	6	20	Bulk
May	6	4	BiOp	June	6	11	SP50	July	7	20	Zero Spill
May	7	4	BiOp	June	7	12	BiOp	July	8	20	Zero Spill
May	8	4	SP50	June	8	12	BiOp	July	9	21	Bulk
May	9	4	SP50	June	9	12	SP50	July	10	21	Zero Spill
May	10	5	BiOp	June	10	12	SP50	July	11	22	Bulk
May	11	5	BiOp	June	11	13	BiOp	July	12		Bulk*
May	12	5	SP50	June	12	13	BiOp	July	13		Surv
May	13	5	SP50	June	13	13	SP50	July	14		Surv
May	14	6	BiOp	June	14	13	SP50	July	15		Surv
May	15	6	BiOp	June	15	14	BiOp	July	16		Zero Spill
May	16	6	SP50	June	16	14	BiOp	July	17		Bulk*
May	17	6	SP50	June	17	14	SP50	July	18		Bulk*
May	18	7	BiOp	June	18	14	SP50	July	19		Bulk*
May	19	7	BiOp	June	19	15	BiOp	July	20		Bulk*
May	20	7	SP50	June	20	15	BiOp	July	21		Bulk*
May	21	7	SP50	June	21	15	SP50	July	22		Bulk*
May	22	8	BiOp	June	22	15	SP50	July	23		Bulk*
May	23	8	BiOp	June	23	16	BiOp	July	24		Bulk*

Surv =special spill conditions for survival test

Table A.2. 2004 Nominal Treatment Schedule at Ice Harbor Dam

Month	Day	Treatment	Month	Day	Treatment	Month	Day	Treatment
April	15	Bulk	May	16	Flat	June	16	FPP
April	16	Bulk	May	17	Bulk	June	17	FPP
April	17	Flat	May	18	Bulk	June	18	Bulk
April	18	Flat	May	19	Flat	June	19	Bulk
April	19	Bulk	May	20	Flat	June	20	FPP
April	20	Bulk	May	21	Bulk	June	21	FPP
April	21	Flat	May	22	Bulk	June	22	Bulk
April	22	Flat	May	23	Flat	June	23	Bulk
April	23	Bulk	May	24	Flat	June	24	FPP
April	24	Bulk	May	25	Bulk	June	25	FPP
April	25	Flat	May	26	Bulk	June	26	Bulk
April	26	Flat	May	27	Flat	June	27	Bulk
April	27	Bulk	May	28	Flat	June	28	FPP
April	28	Bulk	May	29	Bulk	June	29	FPP
April	29	Flat	May	30	Bulk	June	30	Bulk
April	30	Flat	May	31	Flat	July	1	Bulk
May	1	Bulk	June	1	Flat	July	2	FPP
May	2	Bulk	June	2	Bulk	July	3	FPP
May	3	Flat	June	3	Bulk	July	4	Bulk
May	4	Flat	June	4	Flat	July	5	Bulk
May	5	Bulk	June	5	Flat	July	6	FPP
May	6	Bulk	June	6	Bulk	July	7	FPP
May	7	Flat	June	7	Bulk	July	8	Bulk
May	8	Flat	June	8	Flat	July	9	Bulk
May	9	Bulk	June	9	Flat	July	10	FPP
May	10	Bulk	June	10	Bulk	July	11	FPP
May	11	Flat	June	11	Bulk	July	12	Bulk
May	12	Flat	June	12	Flat	July	13	Bulk
May	13	Bulk	June	13	Flat	July	14	FPP
May	14	Bulk	June	14	Bulk	July	15	FPP
May	15	Flat	June	15	Bulk			

Table A.3. 2005 Nominal Treatment Schedule at Ice Harbor Dam. Transition from spring to summer occurred on June 2.

Date	Block	Treatment	Date	Block	Treatment	Date	Block	Treatment
25-Apr	1	Gas Cap	25-May	8	Gas Cap	24-Jun	16	RSW
26-Apr	1	Gas Cap	26-May	8	Gas Cap	25-Jun	16	RSW
27-Apr	1	RSW	27-May	9	Gas Cap	26-Jun	16	Gas Cap
28-Apr	1	RSW	28-May	9	Gas Cap	27-Jun	16	Gas Cap
29-Apr	2	RSW	29-May	9	RSW	28-Jun	17	Gas Cap
30-Apr	2	RSW	30-May	9	RSW	29-Jun	17	Gas Cap
1-May	2	Gas Cap	31-May	10	Gas Cap	30-Jun	17	RSW
2-May	2	Gas Cap	1-Jun	10	Gas Cap	1-Jul	17	RSW
3-May	3	Gas Cap	2-Jun	10	RSW	2-Jul	18	Gas Cap
4-May	3	Gas Cap	3-Jun	10	RSW	3-Jul	18	Gas Cap
5-May	3	RSW	4-Jun	11	RSW	4-Jul	18	RSW
6-May	3	RSW	5-Jun	11	RSW	5-Jul	18	RSW
7-May	4	RSW	6-Jun	11	Gas Cap	6-Jul	19	Gas Cap
8-May	4	RSW	7-Jun	11	Gas Cap	7-Jul	19	Gas Cap
9-May	4	Gas Cap	8-Jun	12	RSW	8-Jul	19	RSW
10-May	4	Gas Cap	9-Jun	12	RSW	9-Jul	19	RSW
11-May	5	RSW	10-Jun	12	Gas Cap	10-Jul	20	Gas Cap
12-May	5	RSW	11-Jun	12	Gas Cap	11-Jul	20	Gas Cap
13-May	5	Gas Cap	12-Jun	13	RSW	12-Jul	20	RSW
14-May	5	Gas Cap	13-Jun	13	RSW	13-Jul	20	RSW
15-May	6	RSW	14-Jun	13	Gas Cap	14-Jul	21	RSW
16-May	6	RSW	15-Jun	13	Gas Cap	15-Jul	21	RSW
17-May	6	Gas Cap	16-Jun	14	Gas Cap	16-Jul	21	Gas Cap
18-May	6	Gas Cap	17-Jun	14	Gas Cap	17-Jul	21	Gas Cap
19-May	7	Gas Cap	18-Jun	14	RSW	18-Jul	22	Gas Cap
20-May	7	Gas Cap	19-Jun	14	RSW	19-Jul	22	Gas Cap
21-May	7	RSW	20-Jun	15	RSW	20-Jul	22	RSW
22-May	7	RSW	21-Jun	15	RSW	21-Jul	22	RSW
23-May	8	RSW	22-Jun	15	Gas Cap			
24-May	8	RSW	23-Jun	15	Gas Cap			

Table A.4. 2006 Nominal Treatment Schedule at Ice Harbor Dam. Transition from spring to summer was May 25 based on the change to subyearling dominance of collection counts.

Date	Block	Treatment	Date	Block	Treatment	Date	Block	Treatment
4/14/2006		Gas Cap	**5/17/2006**	**5**	**Gas Cap**	6/19/2006	13	30%
4/15/2006		Gas Cap	**5/18/2006**	**5**	**Gas Cap**	6/20/2006	13	Gas Cap
4/16/2006		Gas Cap	**5/19/2006**	**5**	**30%**	6/21/2006	13	Gas Cap
4/17/2006		Gas Cap	**5/20/2006**	**5**	**30%**	6/22/2006	14	Gas Cap
4/18/2006		Gas Cap	**5/21/2006**	**6**	**30%**	6/23/2006	14	Gas Cap
4/19/2006		Gas Cap	**5/22/2006**	**6**	**30%**	6/24/2006	14	30%
4/20/2006		Gas Cap	**5/23/2006**	**6**	**Gas Cap**	6/25/2006	14	30%
4/21/2006		Gas Cap	**5/24/2006**	**6**	**Gas Cap**	6/26/2006	15	Gas Cap
4/22/2006		Gas Cap	**5/25/2006**	**7**	**Gas Cap**	6/27/2006	15	Gas Cap
4/23/2006		Gas Cap	5/26/2006	7	Gas Cap	6/28/2006	15	30%
4/24/2006		Gas Cap	5/27/2006	7	30%	6/29/2006	15	30%
4/25/2006		Gas Cap	5/28/2006	7	30%	6/30/2006	16	30%
4/26/2006		Gas Cap	**5/29/2006**	**8**	**30%**	7/1/2006	16	30%
4/27/2006		Gas Cap	**5/30/2006**	**8**	**30%**	7/2/2006	16	Gas Cap
4/28/2006		Gas Cap	**5/31/2006**	**8**	**Gas Cap**	7/3/2006	16	Gas Cap
4/29/2006		Gas Cap	**6/1/2006**	**8**	**Gas Cap**	7/4/2006	17	30%
4/30/2006		Gas Cap	6/2/2006	9	30%	7/5/2006	17	30%
5/1/2006	1	Gas Cap	**6/3/2006**	**9**	**30%**	7/6/2006	17	Gas Cap
5/2/2006	1	Gas Cap	**6/4/2006**	**9**	**Gas Cap**	7/7/2006	17	Gas Cap
5/3 2006	**1**	**30%**	6/5/2006	9	Gas Cap	7/8/2006	18	30%
5/4/2006	1	30%	**6/6/2006**	**10**	**Gas Cap**	7/9/2006	18	30%
5/5/2006	2	30%	**6/7/2006**	**10**	**Gas Cap**	7/10/2006	18	Gas Cap
5/6/2006	2	30%	**6/8/2006**	**10**	**30%**	7/11/2006	18	Gas Cap
5/7/2006	2	Gas Cap	**6/9/2006**	**10**	**30%**	7/12/2006	19	30%
5/8/2006	2	Gas Cap	**6/10/2006**	**11**	**Gas Cap**	7/13/2006	19	30%
5/9/2006	3	Gas Cap	**6/11/2006**	**11**	**Gas Cap**	7/14/2006	19	Gas Cap
5/10/2006	3	Gas Cap	**6/12/2006**	**11**	**30%**	7/15/2006	19	Gas Cap
5/11/2006	3	30%	**6/13/2006**	**11**	**30%**	7/16/2006	20	Gas Cap
5/12/2006	3	30%	6/14/2006	12	Gas Cap	7/17/2006	20	Gas Cap
5/13/2006	4	Gas Cap	6/15/2006	12	Gas Cap	7/18/2006	20	30%
5/14/2006	4	Gas Cap	6/16/2006	12	30%	7/19/2006	20	30%
5/15/2006	4	30%	6/17/2006	12	30%			
5/16/2006	4	30%	6/18/2006	13	30%			

Bolded cells were dropped from treatment comparisons in the hydroacoustic evaluation because treatment conditions were not met.

Appendix B

Tailrace Water Elevation Relationships at Ice Harbor Dam

Appendix B

Tailrace Water Elevation Relationships at Ice Harbor Dam

This appendix presents rating curves that relate tailrace water elevation at Ice Harbor Dam to discharge and downstream pool elevation.

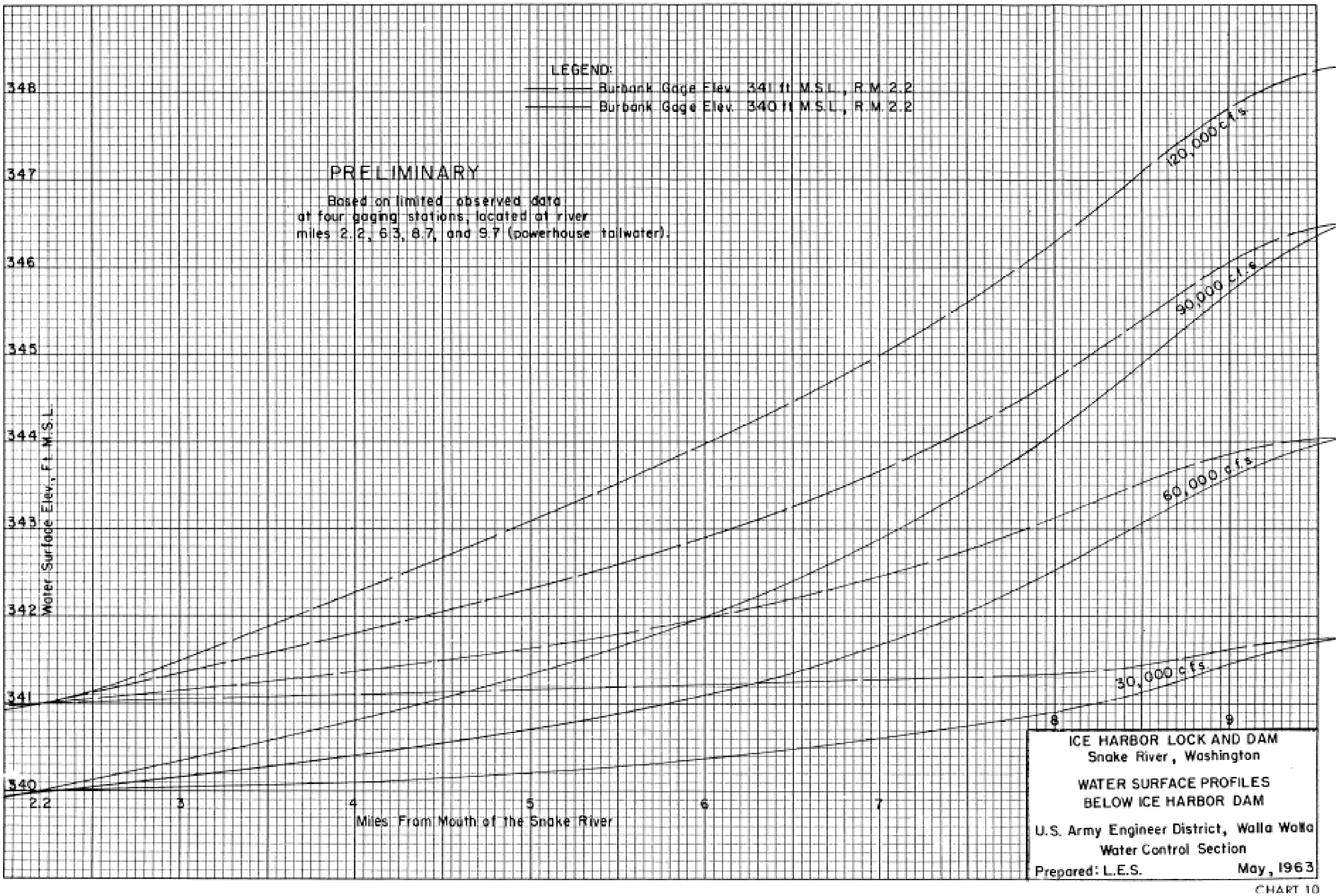

Figure B.1. Ice Harbor Dam Tailrace Water Elevations as a Function of Discharge and Downstream Pool Elevation. Source: USACE Walla Walla District, Water Control Manual for Ice Harbor Lock and Dam (1994) Chart 10.

Appendix C

Annotated Bibliography of Studies at Ice Harbor Dam

Appendix C

Annotated Bibliography of Studies at Ice Harbor Dam

This appendix is an annotated bibliography of studies at Ice Harbor Dam with links to PDFs of the original reports. The text of this appendix can be found on the attached DVD.

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